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APR 79 S W TSAI , H T HAHN
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TI-59 MAGNETIC CARD CALCULATOR SOLUTIONS TO COMPOSITE MATERIALS FORMULAS

MECHANICS AND SURFACE INTERACTIONS BRANCH
NONMETALLIC MATERIALS DIVISION

APRIL 1979

TECHNICAL REPORT AFML-TR-79-4040
Final Report for Period October 1977 to October 1978

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Nonmetallic Materials Division

FOR THE COMMANDER

J. M. Kelble

J. M. KELBLE, Chief
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Properties of Unidirectional & Laminated Composites
In-Plane and Flexural Stiffness & Strength
Nonmechanical Strains

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This volume contains the description and instructions of magnetic cards for TI-59 programmable calculators. These tapes contain the key calculations of the stiffness and strength of unidirectional and symmetrically laminated composites. Both in-plane and flexural loadings can be applied. The initial

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stress and strain due to curing and moisture adsorption are also included in the strength calculation. With the aid of the magnetic cards, instant calculations can be made for practical use. The use of cards is also an effective teaching tool. The formulas used in the cards have been derived in another AFML report, entitled, "Introduction to Composite Materials", AFML-TR-78-201.

FOREWORD

This report was prepared in the Mechanics and Surface Interactions Branch (AFML/MBM), Nonmetallic Materials Division, Air Force Materials Laboratory, Wright-Patterson AFB, Ohio. The work was performed under the support Project No. 2419, "Nonmetallic Structural Materials," Task No. 241903, "Composite Materials and Mechanics Technology." The time period covered by this effort was from October 1977 to October 1978. Stephen W. Tsai (AFML/MBM) was the laboratory project engineer. H. Thomas Hahn was a member of AFML/MBM until 1 August 1978.

The page numbers which appear in the flow charts refer to the pages of this report. The equation number, however, refer to those equations in AFML-TR-78-201, "Introduction to Composite Materials".

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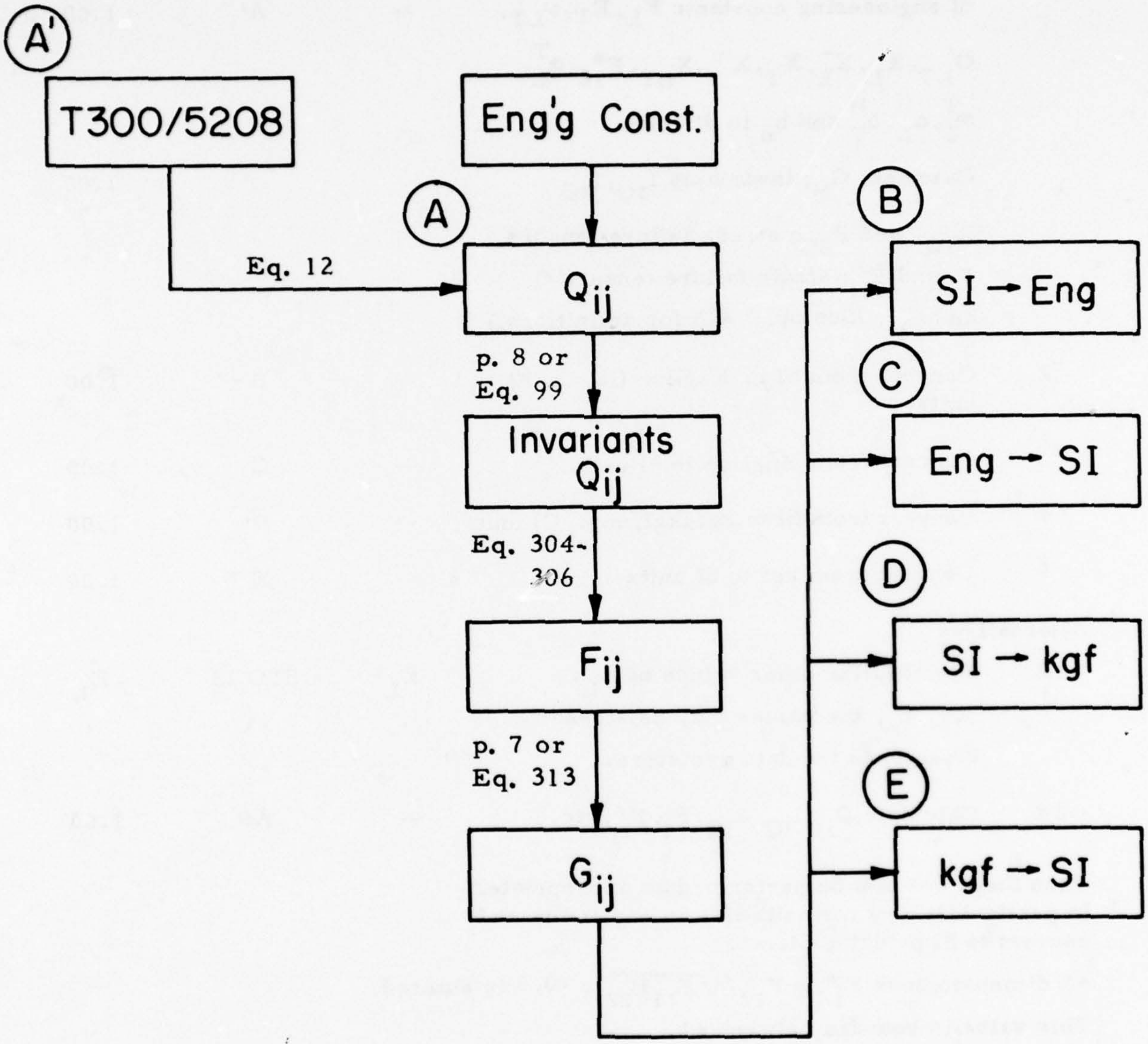
TAPE #1
PROPERTIES OF UNIDIRECTIONAL COMPOSITES



USER INSTRUCTIONS

TAPE #1: PROPERTIES OF UNIDIRECTIONAL COMPOSITES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	For T300/5208 plies, initialize values of engineering constants $E_L, E_T, \nu_{LT}, G_{LT}, X_L, X_L^-, X_T, X^-_T, X_{LT}, F^*_{12}, \alpha_L^T, \alpha_T^T, \alpha_L^H, \alpha_T^H$ and h_o in SI units.	--	A'	1.00
	Calculate Q_{ij}; invariants I_{1Q}, I_{2Q} R_{1Q}, and R_{2Q}; stress failure tensors F_i and F_{ij}; strain failure tensors G_i and G_{ij}. (See pp. 7 & 8 for definitions.)			1.00
2	Convert from SI to English (lb, in, F) units.	--	B	1.00
3	Convert from English to SI units.	--	C	1.00
4	Convert from SI to kgf (kgf, mm, C) units.	--	D	1.00
5	Convert from kgf to SI units	--	E	1.00
Alternatives				
1A	To initialize other values of E_L, ..., h_o, the values may be stored directly in the data registers.	E_L . .	STO 18 . .	E_L . .
2A	Calculate $Q_{ij}, I_{iQ}, R_{iQ}, F_i, F_{ij}$, etc.	--	A	1.00

Then Steps 2-5 can be performed as appropriate. In particular, one can initialize in eng. units and convert to SI by using Step 3.

*A *dimensionless* $F^*_{12} = F_{12}/\sqrt{F_{11}F_{22}} = -0.5$ is entered. This value is bounded between ±1.

Computed ply data should be recorded in blocks 3 and 4 for future use. Tape #1 need not be run, unless a change in unit (e.g. from SI to Eng) or change in properties is desired.

Tape# 1 Title PROPERTIES OF UNIDIRECTIONAL COMPOSITES (T300/5208)

KEYS	STORAGE MEMORIES					
A Initialize(after entering Eng'g Constants)	0		20	ν_{LT}	40	
	1	Q_{11}	21	G_{LT}	41	h_o
A' Initialize T300/5208 (SI)	2	Q_{22}	22	α_L^T	42	I_{1Q}
	3	Q_{12}	23	α_T^T	43	I_{2Q}
B SI $\rightarrow$ English (Pa) (psi)	4		24	α_L^H	44	R_{1Q}
	5		25	α_T^H	45	R_{2Q}
B'	6		26		46	F_{11}
	7		27	Q_{11}	47	F_1
C Eng $\rightarrow$ SI (psi) (Pa)	8		28	Q_{22}	48	F_{22}
	9		29	Q_{12}	49	F_2
C'	10		30	Q_{66}	50	$F_{12}^* = F_{12}/\sqrt{F_{11}F_{22}}$
	11		31		51	F_{12}
D SI $\rightarrow$ kgf (Pa) (kgf/mm^2)	12		32		52	
	13	X_L	33		53	
D'	14	X_L^-	34		54	G_{11}
	15	X_T	35		55	G_{22}
E kgf $\rightarrow$ SI (kgf/mm^2) (Pa)	16	X_T^-	36		56	G_{12}
	17	X_{LT}	37		57	G_{66}
E'	18	E_L	38		58	G_1
	19	E_T	39	m	59	G_2

Tape #1 Properties of Unidirectional

T300-5208

```
000  76 LBL
001  16 A'
002  01  1
003  08  8
004  66 PAU
005  57 ENG
006  01  1
007  08  8
008  01  1
009  52 EE
010  09  9
011  42 STO
012  18  18
013  01  1
014  00  0
015  03  3
016  52 EE
017  08  8
018  42 STO
019  19  19
020  93  .
021  02  2
022  08  8
023  42 STO
024  20  20
025  07  7
026  01  1
027  07  7
028  52 EE
029  07  7
030  42 STO
031  21  21
032  01  1
033  05  5
034  52 EE
035  08  8
036  42 STO
037  13  13
038  42 STO
039  14  14
040  04  4
041  52 EE
042  07  7
043  42 STO
044  15  15
045  02  2
046  04  4
047  06  6
048  52 EE
049  06  6
050  42 STO
051  16  16
052  06  6
053  08  8
054  52 EE
055  06  6
056  42 STO
057  17  17
058  93  .
059  05  5
060  94 +/-
061  42 STO
062  50  50
063  01  1
064  52 EE
065  94 +/-
066  08  8
067  42 STO
068  22  22
069  01  1
070  02  2
071  05  5
072  52 EE
073  94 +/-
074  07  7
075  42 STO
076  23  23
077  00  0
078  42 STO
079  24  24
```

```
080  93  .
081  06  6
082  42 STO
083  25  25
084  01  1
085  02  2
086  05  5
087  52 EE
088  94 +/-
089  06  6
090  42 STO
091  41  41
092  76 LBL
```

Q_{ij}

```
093  11 A
094  57 ENG
095  43 RCL
096  20  20
097  33 X²
098  65  ×
099  43 RCL
100  19  19
101  55  ÷
102  43 RCL
103  18  18
104  75  -
105  01  1
106  95  =
107  94 +/-
108  35 1/X
109  42 STO
110  39  39
111  65  ×
112  43 RCL
113  18  18
114  95  =
115  42 STO
116  27  27
117  42 STO
118  01  01
119  43 RCL
120  39  39
121  65  ×
122  43 RCL
123  19  19
124  95  =
125  42 STO
126  28  28
127  42 STO
128  02  02
129  65  ×
130  43 RCL
131  20  20
132  95  =
133  42 STO
134  29  29
135  42 STO
136  03  03
137  43 RCL
138  21  21
139  42 STO
140  30  30
141  65  ×
142  04  4
143  75  -
144  02  2
145  65  ×
146  43 RCL
147  29  29
148  85  +
149  43 RCL
150  27  27
151  85  +
152  43 RCL
153  28  28
154  95  =
155  55  ÷
156  08  8
157  95  =
158  42 STO
159  43  43
```

```
160  75  -
161  43 RCL
162  30  30
163  95  =
164  42 STO
165  45  45
166  43 RCL
167  27  27
168  85  +
169  43 RCL
170  28  28
171  85  +
172  02  2
173  65  ×
174  43 RCL
175  29  29
176  95  =
177  55  ÷
178  04  4
179  95  =
180  42 STO
181  42  42
182  43 RCL
183  27  27
184  75  -
185  43 RCL
186  28  28
187  95  =
188  50 I×I
189  55  ÷
190  02  2
191  95  =
192  42 STO
193  44  44
```

F_{ij}

```
194  43 RCL
195  13  13
196  65  ×
197  43 RCL
198  14  14
199  95  =
200  35 1/X
201  42 STO
202  46  46
203  65  ×
204  43 RCL
205  14  14
206  75  -
207  43 RCL
208  14  14
209  35 1/X
210  95  =
211  42 STO
212  47  47
213  43 RCL
214  15  15
215  65  ×
216  43 RCL
217  16  16
218  95  =
219  35 1/X
220  42 STO
221  48  48
222  65  ×
223  43 RCL
224  46  46
225  95  =
226  34 √X
227  65  ×
228  43 RCL
229  50  50
230  95  =
231  42 STO
232  51  51
233  43 RCL
234  15  15
235  35 1/X
236  75  -
237  43 RCL
238  16  16
239  35 1/X
```

Tape #1 Properties of Unidirectional

	Step	Code	Key
	240	95	=
	241	42	STO
	242	49	49
G_{ij}	243	43	RCL
	244	30	30
	245	55	÷
	246	43	RCL
	247	17	17
	248	95	=
	249	33	X²
	250	42	STO
	251	57	57
	252	43	RCL
	253	46	46
	254	65	×
	255	43	RCL
	256	27	27
	257	33	X²
	258	85	+
	259	02	2
	260	65	×
	261	43	RCL
	262	51	51
	263	65	×
	264	43	RCL
	265	27	27
	266	65	×
	267	43	RCL
	268	29	29
	269	85	+
	270	43	RCL
	271	48	48
	272	65	×
	273	43	RCL
	274	29	29
	275	33	X²
	276	95	=
	277	42	STO
	278	54	54
	279	43	RCL
	280	46	46
	281	65	×
	282	43	RCL
	283	29	29
	284	33	X²
	285	85	+
	286	02	2
	287	65	×
	288	43	RCL
	289	51	51
	290	65	×
	291	43	RCL
	292	29	29
	293	65	×
	294	43	RCL
	295	28	28
	296	85	+
	297	43	RCL
	298	48	48
	299	65	×
	300	43	RCL
	301	28	28
	302	33	X²
	303	95	=
	304	42	STO
	305	55	55
	306	43	RCL
	307	46	46
	308	65	×
	309	43	RCL
	310	27	27
	311	65	×
	312	43	RCL
	313	29	29
	314	85	+
	315	43	RCL
	316	51	51
	317	65	×
	318	43	RCL
	319	27	27

	Step	Code	Key
	320	65	×
	321	43	RCL
	322	28	28
	323	85	+
	324	43	RCL
	325	51	51
	326	65	×
	327	43	RCL
	328	29	29
	329	33	X²
	330	85	+
	331	43	RCL
	332	48	48
	333	65	×
	334	43	RCL
	335	28	28
	336	65	×
	337	43	RCL
	338	29	29
	339	95	=
	340	42	STO
	341	56	56
	342	43	RCL
	343	47	47
	344	65	×
	345	43	RCL
	346	27	27
	347	85	+
	348	43	RCL
	349	49	49
	350	65	×
	351	43	RCL
	352	29	29
	353	95	=
	354	42	STO
	355	58	58
	356	43	RCL
	357	47	47
	358	65	×
	359	43	RCL
	360	29	29
	361	85	+
	362	43	RCL
	363	49	49
	364	65	×
	365	43	RCL
	366	28	28
	367	95	=
	368	42	STO
	369	59	59
	370	01	1
	371	95	=
	372	91	R/S
SI → English	373	76	LBL
	374	12	B
	375	06	6
	376	08	8
	377	09	9
	378	05	5
	379	35	1/X
	380	42	STO
	381	40	40
	382	05	5
	383	55	÷
	384	09	9
	385	95	=
	386	49	PRD
	387	22	22
	388	49	PRD
	389	23	23
	390	03	3
	391	09	9
	392	93	.
	393	04	4
	394	49	PRD
	395	41	41
	396	71	SBR
	397	34	ΓX
Eng → SI	398	76	LBL
	399	13	C

	Step	Code	Key
	400	06	6
	401	08	8
	402	09	9
	403	05	5
	404	42	STO
	405	40	40
	406	09	9
	407	55	÷
	408	05	5
	409	95	=
	410	49	PRD
	411	22	22
	412	49	PRD
	413	23	23
	414	03	3
	415	09	9
	416	93	.
	417	04	4
	418	35	1/X
	419	49	PRD
	420	41	41
	421	71	SBR
	422	34	ΓX
SI → kgf	423	76	LBL
	424	14	D
	425	09	9
	426	08	8
	427	01	1
	428	52	EE
	429	04	4
	430	35	1/X
	431	42	STO
	432	40	40
	433	01	1
	434	52	EE
	435	03	3
	436	49	PRD
	437	41	41
Conversion	438	76	LBL
	439	34	ΓX
	440	43	RCL
	441	40	40
	442	49	PRD
	443	13	13
	444	49	PRD
	445	14	14
	446	49	PRD
	447	15	15
	448	49	PRD
	449	16	16
	450	49	PRD
	451	17	17
	452	49	PRD
	453	18	18
	454	49	PRD
	455	19	19
	456	49	PRD
	457	21	21
	458	61	GTO
	459	00	00
	460	92	92
kgf → SI	461	76	LBL
	462	15	E
	463	09	9
	464	08	8
	465	01	1
	466	52	EE
	467	04	4
	468	42	STO
	469	40	40
	470	01	1
	471	52	EE
	472	03	3
	473	35	1/X
	474	49	PRD
	475	41	41
	476	71	SBR
	477	34	ΓX
	478	00	0
	479	00	0

Tape #1 Properties of Unidirectional/Sample Problems

	T300/5208 SI	T300/5208 ENG.		AS/3501 SI	AS/3501 ENG.	
	0. 00	0. 00	00	0. 00	0. 00	00
	181.81114 09	26.368548 06	01	138.78041 09	20.127688 06	01
	10.346159 09	1.5005306 06	02	9.0162185 09	1.3076459 06	02
	2.8969244 09	420.14858 03	03	2.7048656 09	392.29377 03	03
	0. 00	0. 00	04	0. 00	0. 00	04
	0. 00	0. 00	05	0. 00	0. 00	05
	0. 00	0. 00	06	0. 00	0. 00	06
	0. 00	0. 00	07	0. 00	0. 00	07
	0. 00	0. 00	08	0. 00	0. 00	08
	0. 00	0. 00	09	0. 00	0. 00	09
	0. 00	0. 00	10	0. 00	0. 00	10
	0. 00	0. 00	11	0. 00	0. 00	11
	0. 00	0. 00	12	0. 00	0. 00	12
	1.5 09	217.54895 03	13	1.44795 09	210. 03	13
	1.5 09	217.54895 03	14	1.44795 09	210. 03	14
	40. 06	5.8013053 03	15	51.7125 06	7.5 03	15
	246. 06	35.678028 03	16	206.85 06	30. 03	16
	68. 06	9.862219 03	17	93.0825 06	13.5 03	17
	181. 09	26.250906 06	18	137.96895 09	20.01 06	18
	10.3 09	1.4938361 06	19	8.9635 09	1.3 06	19
	280. -03	280. -03	20	300. -03	300. -03	20
	7.17 09	1.039884 06	21	7.10185 09	1.03 06	21
	10. -09	5.5555556-09	22	10. -09	5.5555556-09	22
	12.5-06	6.9444444-06	23	12.5-06	6.9444444-06	23
	0. 00	0. 00	24	0. 00	0. 00	24
	600. -03	600. -03	25	600. -03	600. -03	25
	0. 00	0. 00	26	0. 00	0. 00	26
	181.81114 09	26.368548 06	27	138.78041 09	20.127688 06	27
	10.346159 09	1.5005306 06	28	9.0162185 09	1.3076459 06	28
	2.8969244 09	420.14858 03	29	2.7048656 09	392.29377 03	29
Q_{ij}	7.17 09	1.039884 06	30	7.10185 09	1.03 06	30
	0. 00	0. 00	31	0. 00	0. 00	31
	0. 00	0. 00	32	0. 00	0. 00	32
	0. 00	0. 00	33	0. 00	0. 00	33
	0. 00	0. 00	34	0. 00	0. 00	34
	0. 00	0. 00	35	0. 00	0. 00	35
	0. 00	0. 00	36	0. 00	0. 00	36
	0. 00	0. 00	37	0. 00	0. 00	37
	0. 00	0. 00	38	0. 00	0. 00	38
	1.0044814 00	1.0044814 00	39	1.0058815 00	1.0058815 00	39
	0. 00	145.03263-06	40	6.895 03	145.03263-06	40
	125. -06	4.92125-03	41	133.24846-06	5.2499895-03	41
	49.487787 09	7.177344 06	42	38.30159 09	5.5549804 06	42
	26.880431 09	3.8985397 06	43	21.349287 09	3.0963433 06	43
	85.73249 09	12.434009 06	44	64.882096 09	9.4100211 06	44
	19.710431 09	2.8586557 06	45	14.247437 09	2.0663433 06	45
	444.44444-21	21.129344-12	46	476.97198-21	22.675737-12	46
	0. 00	-1. -18	47	-100. -24	0. 00	47
	101.62602-18	4.831405-09	48	93.486509-18	4.4444444-09	48
	20.934959-09	144.34654-06	49	14.503263-09	100. -06	49
	-500. -03	-500. -03	50	-500. -03	-500. -03	50
	-3.3603243-18	-159.75326-12	51	-3.3388039-18	-158.73016-12	51
	0. 00	0. 00	52	0. 00	0. 00	52
	0. 00	0. 00	53	0. 00	0. 00	53
	12.004384 03	12.004384 03	54	7.3638004 03	7.3638004 03	54
	10.680652 03	10.680652 03	55	7.4403621 03	7.4403621 03	55
G_{ij}	-3.0691032 03	-3.0691032 03	56	-1.7432239 03	-1.7432239 03	56
	11.117842 03	11.117842 03	57	5.8211248 03	5.8211248 03	57
	60.646995 00	60.646995 00	58	39.229377 00	39.229377 00	58
	216.59641 00	216.59641 00	59	130.76459 00	130.76459 00	59

TAPE #1

TENSOR POLYNOMIAL FAILURE CRITERION IN STRAIN SPACE

Find: $G_{ij}\epsilon_i\epsilon_j + G_i\epsilon_i = 1$

From: $F_{ij}\sigma_i\sigma_j + F_i\sigma_i = 1$

and $\sigma_i = Q_{ij}\epsilon_j$

we have $G_{ij} = Q_{ik}Q_{j\ell}F_{k\ell}$

$G_i = Q_{ik}F_k$

For orthotropic materials: $Q_{16} = Q_{26} = 0$

$$G_{11} = F_{11}Q_{11}^2 + 2F_{12}Q_{11}Q_{21} + F_{22}Q_{12}^2$$

$$G_{22} = F_{11}Q_{12}^2 + 2F_{12}Q_{12}Q_{22} + F_{22}Q_{22}^2$$

$$G_{66} = F_{66}Q_{66}^2 = \left(\frac{Q_{66}}{X_{LT}}\right)^2$$

$$G_{12} = F_{11}Q_{11}Q_{12} + F_{12}(Q_{11}Q_{22} + Q_{12}^2) + F_{22}Q_{21}Q_{22}$$

$$G_{16} = G_{26} = 0$$

$$G_1 = F_1Q_{11} + F_2Q_{21}$$

$$G_2 = F_1Q_{12} + F_2Q_{22}$$

$$G_6 = 0$$

TAPE #1

DEFINITIONS OF INVARIANTS OF ELASTIC MODULUS

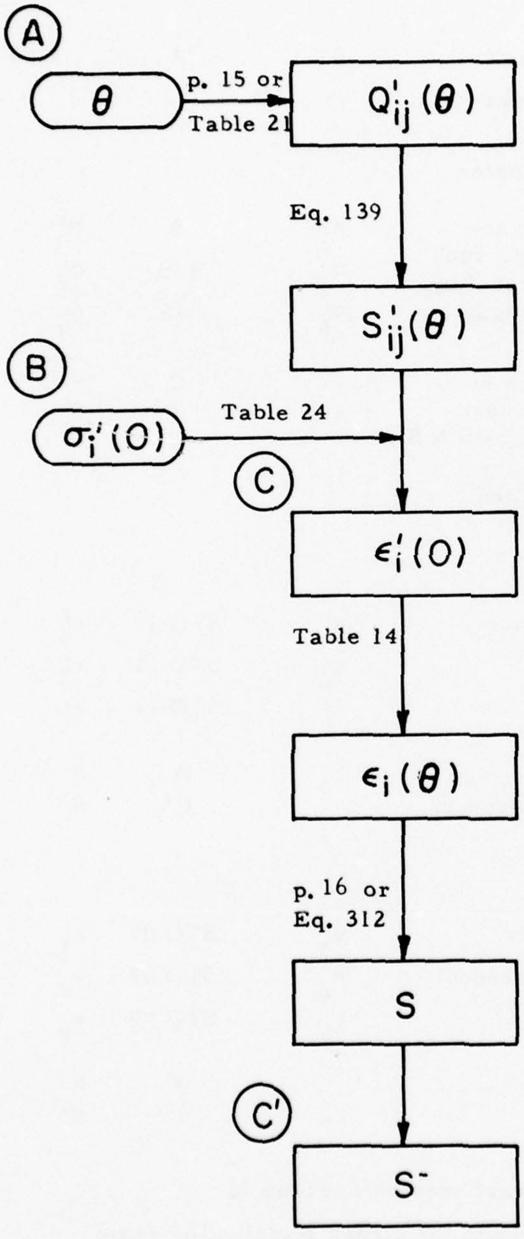
$$I_{1Q} = \frac{1}{2}(Q_{11} + Q_{22} - 2Q_{12}) = (U_1 + U_4) / 2$$

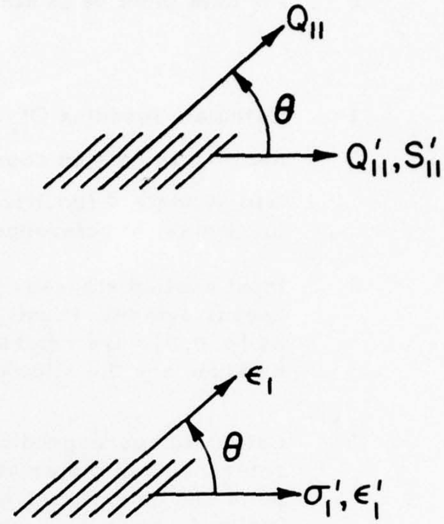
$$I_{2Q} = \frac{1}{4}(Q_{11} + Q_{22} - 2Q_{12} + 4Q_{66}) = U_5 = (U_1 - U_4) / 2$$

$$R_{1Q} = U_2$$

$$R_{2Q} = U_3$$

TAPE #2
OFF-AXIS PROPERTIES OF UNIDIRECTIONAL COMPOSITES





$$S = \frac{\sigma_{allowed}}{\sigma_{imposed}} = \frac{\epsilon_{allowed}}{\epsilon_{imposed}}$$

$$S^- = \frac{\sigma^-_{allowed}}{-\sigma_{imposed}} = \frac{\epsilon^-_{allowed}}{-\epsilon_{imposed}}$$

USER INSTRUCTIONS

TAPE #2: OFF-AXIS PROPERTIES OF UNIDIRECTIONAL COMPOSITES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
0	Ply data must be in storage			
1	Calculate modulus Q'_{ij} and compliance S'_{ij} in rotated coordinate system at angle θ (positive counterclockwise) to reference coordinates	θ	A	1.00
2	Input applied stresses in reference coord. system. If unit stresses, such as [1,0,0], are entered, the resulting S values are the allowable strengths.	σ'_1 σ'_2 σ'_6	B R/S R/S	σ'_1 σ'_2 σ'_6
3*	Calculate corresponding strains in reference and material coord. systems and calculate strength ratios S & S^-. (defined as the ratios by which the applied loading must be multiplied to reach the failure surface).	-- --	C C'	S S^-
Alternative A				
2A	Input applied strains in reference coord. system	ϵ'_1 ϵ'_2 ϵ'_6	STO 10 STO 11 STO 12	ϵ'_1 ϵ'_2 ϵ'_6
3A	Calculate strains in material coord. system, and calculate strength-strain ratios S and S^-.	-- --	D C'	S S^-
Alternative B				
2B	Input strains in material coords. (Step 0 needed, but Step 1 not needed)	ϵ_1 ϵ_2 ϵ_6	STO 07 STO 08 STO 09	ϵ_1 ϵ_2 ϵ_6
3B	Calculate strength ratios S & S^-.	-- --	E C'	S S^-

* Steps 0, 1 and 2 must be executed at least once before Step 3. If only the angle in Step 1 is changed while the stress remains the same Step 2 can be skipped. If the stress is changed while the angle remains constant, Step 1 can be omitted.

Tape* 2 Title OFF-AXIS PROPERTIES OF UNIDIRECTIONAL COMPOSITES

KEYS	STORAGE MEMORIES					
A θ	0	θ	20		40	4θ
	1	σ'_1	21		41	h_o
A'	2	σ'_2	22		42	I_{1Q}
	3	σ'_6	23		43	I_{2Q}
B σ'_i	4		24		44	R_{1Q}
	5		25		45	R_{2Q}
B'	6		26	$\lvert Q \rvert$	46	
	7	ϵ_1	27	Q'_{11}	47	
C S	8	ϵ_2	28	Q'_{22}	48	
	9	ϵ_6	29	Q'_{12}	49	
C' S^-	10	ϵ'_1	30	Q'_{66}	50	
	11	ϵ'_2	31	Q'_{16}	51	
D S from ϵ'_i	12	ϵ'_6	32	Q'_{26}	52	... S
	13		33	S'_{11}	53	... S^-
D'	14		34	S'_{22}	54	G_{11}
	15		35	S'_{12}	55	G_{22}
E S from ϵ_i	16		36	S'_{66}	56	G_{12}
	17		37	S'_{16}	57	G_{66}
E'	18		38	S'_{26}	58	G_1
	19		39	2θ	59	G_2

Tape #2 Off-Axis Properties

θ

```
000 76 LBL
001 11 A
002 57 ENG
003 42 STO
004 00 00
005 65 ×
006 02 2
007 95 =
008 42 STO
009 39 39
010 65 ×
011 02 2
012 95 =
013 42 STO
014 40 40
015 01 1
016 06 6
017 66 PAU
```

Q'_{ij}

```
018 43 RCL
019 42 42
020 85 +
021 43 RCL
022 43 43
023 85 +
024 43 RCL
025 39 39
026 39 COS
027 65 ×
028 43 RCL
029 44 44
030 85 +
031 43 RCL
032 40 40
033 39 COS
034 65 ×
035 43 RCL
036 45 45
037 95 =
038 42 STO
039 27 27
040 75 -
041 43 RCL
042 39 39
043 39 COS
044 65 ×
045 02 2
046 65 ×
047 43 RCL
048 44 44
049 95 =
050 42 STO
051 28 28
052 43 RCL
053 42 42
054 75 -
055 43 RCL
056 43 43
057 75 -
058 43 RCL
059 40 40
060 39 COS
061 65 ×
062 43 RCL
063 45 45
064 95 =
065 42 STO
066 29 29
067 85 +
068 02 2
069 65 ×
070 43 RCL
071 43 43
072 75 -
073 43 RCL
074 42 42
075 95 =
076 42 STO
077 30 30
078 43 RCL
079 39 39
080 38 SIN
081 55 ÷
082 02 2
083 65 ×
084 43 RCL
085 44 44
086 95 =
087 85 +
088 43 RCL
089 40 40
090 38 SIN
091 65 ×
092 43 RCL
093 45 45
094 95 =
095 42 STO
096 31 31
097 75 -
098 43 RCL
099 39 39
100 38 SIN
101 65 ×
102 43 RCL
103 44 44
104 95 =
105 94 +/-
106 42 STO
107 32 32
```

|Q|

```
108 43 RCL
109 27 27
110 65 ×
111 43 RCL
112 28 28
113 65 ×
114 43 RCL
115 30 30
116 85 +
117 43 RCL
118 29 29
119 65 ×
120 43 RCL
121 31 31
122 65 ×
123 43 RCL
124 32 32
125 65 ×
126 02 2
127 75 -
128 43 RCL
129 28 28
130 65 ×
131 43 RCL
132 31 31
133 33 X²
134 75 -
135 43 RCL
136 27 27
137 65 ×
138 43 RCL
139 32 32
140 33 X²
141 75 -
142 43 RCL
143 30 30
144 65 ×
145 43 RCL
146 29 29
147 33 X²
148 95 =
149 42 STO
150 26 26
```

S'^{*}_{ij}

```
151 43 RCL
152 28 28
153 65 ×
154 43 RCL
155 30 30
156 75 -
157 43 RCL
158 32 32
159 33 X²
160 95 =
161 42 STO
162 33 33
163 43 RCL
164 27 27
165 65 ×
166 43 RCL
167 28 28
168 75 -
169 43 RCL
170 29 29
171 33 X²
172 95 =
173 42 STO
174 36 36
175 43 RCL
176 27 27
177 65 ×
178 43 RCL
179 30 30
180 75 -
181 43 RCL
182 31 31
183 33 X²
184 95 =
185 42 STO
186 34 34
187 43 RCL
188 29 29
189 65 ×
190 43 RCL
191 32 32
192 75 -
193 43 RCL
194 28 28
195 65 ×
196 43 RCL
197 31 31
198 95 =
199 42 STO
200 37 37
201 43 RCL
202 31 31
203 65 ×
204 43 RCL
205 32 32
206 75 -
207 43 RCL
208 29 29
209 65 ×
210 43 RCL
211 30 30
212 95 =
213 42 STO
214 35 35
215 43 RCL
216 29 29
217 65 ×
218 43 RCL
219 31 31
220 75 -
221 43 RCL
222 27 27
223 65 ×
224 43 RCL
225 32 32
226 95 =
227 42 STO
228 38 38
```

S'_{ij}

```
229 43 RCL
230 26 26
231 35 1/X
232 49 PRD
233 33 33
234 49 PRD
235 34 34
236 49 PRD
237 35 35
238 49 PRD
239 36 36
```

Tape #2 Off-Axis Properties

```
240 49 PRD
241 37 37
242 49 PRD
243 38 38
244 01 1
245 95 =
246 91 R/S
```

σ_i'

```
247 76 LBL
248 12 B
249 42 STO
250 01 01
251 91 R/S
252 42 STO
253 02 02
254 91 R/S
255 42 STO
256 03 03
257 91 R/S
```

ϵ_i'

```
258 76 LBL
259 13 C
260 01 1
261 04 4
262 66 PAU
263 43 RCL
264 03 03
265 65 ×
266 43 RCL
267 37 37
268 85 +
269 43 RCL
270 02 02
271 65 ×
272 43 RCL
273 35 35
274 85 +
275 43 RCL
276 01 01
277 65 ×
278 43 RCL
279 33 33
280 95 =
281 42 STO
282 10 10
283 43 RCL
284 01 01
285 65 ×
286 43 RCL
287 35 35
288 85 +
289 43 RCL
290 02 02
291 65 ×
292 43 RCL
293 34 34
294 85 +
295 43 RCL
296 03 03
297 65 ×
298 43 RCL
299 38 38
300 95 =
301 42 STO
302 11 11
303 43 RCL
304 01 01
305 65 ×
306 43 RCL
307 37 37
308 85 +
309 43 RCL
310 02 02
311 65 ×
312 43 RCL
313 38 38
314 85 +
315 43 RCL
316 03 03
317 65 ×
318 43 RCL
319 36 36
```

```
320 95 =
321 42 STO
322 12 12
```

$\epsilon_i(\theta)$

```
323 76 LBL
324 14 D
325 43 RCL
326 00 00
327 39 COS
328 33 X²
329 65 ×
330 43 RCL
331 10 10
332 85 +
333 43 RCL
334 00 00
335 38 SIN
336 33 X²
337 65 ×
338 43 RCL
339 11 11
340 85 +
341 43 RCL
342 00 00
343 39 COS
344 65 ×
345 43 RCL
346 00 00
347 38 SIN
348 65 ×
349 43 RCL
350 12 12
351 95 =
352 42 STO
353 07 07
354 75 -
355 43 RCL
356 10 10
357 75 -
358 43 RCL
359 11 11
360 95 =
361 94 +/-
362 42 STO
363 08 08
364 43 RCL
365 11 11
366 75 -
367 43 RCL
368 10 10
369 95 =
370 65 ×
371 43 RCL
372 39 39
373 38 SIN
374 85 +
375 43 RCL
376 39 39
377 39 COS
378 65 ×
379 43 RCL
380 12 12
381 95 =
382 42 STO
383 09 09
```

S

```
384 76 LBL
385 15 E
386 43 RCL
387 54 54
388 65 ×
389 43 RCL
390 07 07
391 33 X²
392 85 +
393 02 2
394 65 ×
395 43 RCL
396 56 56
397 65 ×
398 43 RCL
399 07 07
```

```
400 65 ×
401 43 RCL
402 08 08
403 85 +
404 43 RCL
405 55 55
406 65 ×
407 43 RCL
408 08 08
409 33 X²
410 85 +
411 43 RCL
412 57 57
413 65 ×
414 43 RCL
415 09 09
416 33 X²
417 95 =
418 42 STO
419 52 52
420 43 RCL
421 58 58
422 65 ×
423 43 RCL
424 07 07
425 85 +
426 43 RCL
427 59 59
428 65 ×
429 43 RCL
430 08 08
431 95 =
432 42 STO
433 53 53
434 43 RCL
435 52 52
436 35 1/X
437 42 STO
438 52 52
439 65 ×
440 43 RCL
441 53 53
442 55 ÷
443 02 2
444 95 =
445 42 STO
446 53 53
447 33 X²
448 85 +
449 43 RCL
450 52 52
451 95 =
452 34 √X
453 42 STO
454 52 52
455 85 +
456 43 RCL
457 53 53
458 95 =
459 94 +/-
460 42 STO
461 53 53
462 85 +
463 02 2
464 65 ×
465 43 RCL
466 52 52
467 95 =
468 42 STO
469 52 52
470 91 R/S
```

S^-

```
471 76 LBL
472 18 C'
473 43 RCL
474 53 53
475 91 R/S
476 00 0
477 00 0
478 00 0
479 00 0
```

Tape #2 Off-Axis Properties/Sample Problems

	Register				
θ	00	0. 00	15. 00	30. 00	45. 00
σ_i'	01	1. 00	1. 00	1. 00	1. 00
	02	0. 00	0. 00	0. 00	0. 00
	03	0. 00	0. 00	0. 00	0. 00
	04	0. 00	0. 00	0. 00	0. 00
	05	0. 00	0. 00	0. 00	0. 00
	06	0. 00	0. 00	0. 00	0. 00
	07	5.5248619-12	5.0511395-12	3.7569061-12	1.9889503-12
	08	-1.5469613-12	5.0602866-12	23.111624-12	47.770209-12
	09	0. 00	-34.867503-12	-60.392288-12	-69.735007-12
	10	5.5248619-12	13.768628-12	34.746213-12	59.747083-12
	11	-1.5469613-12	-3.657202-12	-7.8776833-12	-9.987924-12
	12	0. 00	-30.200717-12	-46.957821-12	-45.781258-12
	13	1.5 09	1.5 09	1.5 09	1.5 09
	14	1.5 09	1.5 09	1.5 09	1.5 09
	15	40. 06	40. 06	40. 06	40. 06
	16	246. 06	246. 06	246. 06	246. 06
	17	68. 06	68. 06	68. 06	68. 06
	18	181. 09	181. 09	181. 09	181. 09
	19	10.3 09	10.3 09	10.3 09	10.3 09
	20	280. -03	280. -03	280. -03	280. -03
	21	7.17 09	7.17 09	7.17 09	7.17 09
	22	10. -09	10. -09	10. -09	10. -09
	23	12.5-06	12.5-06	12.5-06	12.5-06
	24	0. 00	0. 00	0. 00	0. 00
	25	600. -03	600. -03	600. -03	600. -03
	26	13.426934 30	13.426934 30	13.426934 30	13.426934 30
Q_{ij}'	27	181.81114 09	160.46995 09	109.37925 09	56.657787 09
	28	10.346159 09	11.976919 09	23.646757 09	56.657787 09
	29	2.8969244 09	12.75214 09	32.462571 09	42.317787 09
	30	7.17 09	17.025216 09	36.735647 09	46.590862 09
	31	0. 00	38.502857 09	54.192991 09	42.866245 09
	32	0. 00	4.3633885 09	20.053523 09	42.866245 09
S_{ij}'	33	5.5248619-12	13.768628-12	34.746213-12	59.747083-12
	34	97.087379-12	93.064094-12	80.527471-12	59.747083-12
	35	-1.5469613-12	-3.657202-12	-7.8776833-12	-9.987924-12
	36	139.47001-12	131.02905-12	114.14713-12	105.70616-12
	37	0. 00	-30.200717-12	-46.957821-12	-45.781258-12
	38	0. 00	-15.580541-12	-32.337645-12	-45.781258-12
	39	0. 00	30. 00	60. 00	90. 00
	40	0. 00	60. 00	120. 00	180. 00
	41	125. -06	125. -06	125. -06	125. -06
	42	49.487787 09	49.487787 09	49.487787 09	49.487787 09
	43	26.880431 09	26.880431 09	26.880431 09	26.880431 09
	44	85.73249 09	85.73249 09	85.73249 09	85.73249 09
	45	19.710431 09	19.710431 09	19.710431 09	19.710431 09
	46	444.44444-21	444.44444-21	444.44444-21	444.44444-21
	47	0. 00	0. 00	0. 00	0. 00
	48	101.62602-18	101.62602-18	101.62602-18	101.62602-18
	49	20.934959-09	20.934959-09	20.934959-09	20.934959-09
	50	-500. -03	-500. -03	-500. -03	-500. -03
	51	-3.3603243-18	-3.3603243-18	-3.3603243-18	-3.3603243-18
S	52	1.5 09	222.22216 06	101.22462 06	64.536588 06
	53	1.5 09	322.82798 06	215.27228 06	198.9018 06
	54	12.004384 03	12.004384 03	12.004384 03	12.004384 03
	55	10.680652 03	10.680652 03	10.680652 03	10.680652 03
	56	-3.0691032 03	-3.0691032 03	-3.0691032 03	-3.0691032 03
	57	11.117842 03	11.117842 03	11.117842 03	11.117842 03
	58	60.646995 00	60.646995 00	60.646995 00	60.646995 00
	59	216.59641 00	216.59641 00	216.59641 00	216.59641 00

TAPE #2

TRANSFORMATION OF MODULUS COMPONENTS

	I_{1Q}	I_{2Q}	R_{1Q}	R_{2Q}
Q'_{11}	1	1	$\cos 2\theta$	$\cos 4\theta$
Q'_{22}	1	1	$-\cos 2\theta$	$\cos 4\theta$
Q'_{12}	1	-1		$-\cos 4\theta$
Q'_{66}		1		$-\cos 4\theta$
Q'_{16}			$\frac{1}{2}\sin 2\theta$	$\sin 4\theta$
Q'_{26}			$\frac{1}{2}\sin 2\theta$	$-\sin 4\theta$

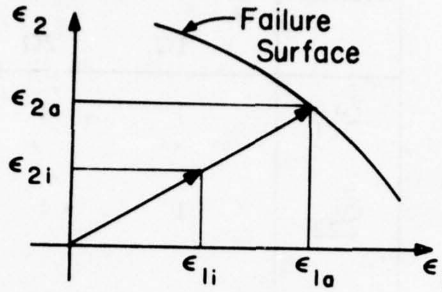
$$Q'_{22} = Q'_{11} - 2R_{1Q}\cos 2\theta$$

$$Q'_{26} = Q'_{16} - 2R_{2Q}\sin 4\theta$$

TAPE #2

STRENGTH RATIOS FOR UNIDIRECTIONAL COMPOSITES

Define $S = \dfrac{\epsilon_{allowed}}{\epsilon_{imposed}} = \dfrac{\epsilon_a}{\epsilon_i}$



Proportional loading is assumed; i.e.

$$\frac{\epsilon_{1a}}{\epsilon_{1i}} = \frac{\epsilon_{2a}}{\epsilon_{2i}} = \frac{\epsilon_{6a}}{\epsilon_{6i}} = S$$

Since linearly elastic behavior up to failure is also assumed,

$$S = \frac{\epsilon_a}{\epsilon_i} = \frac{\sigma_{allowed}}{\sigma_{imposed}}$$

Failure occurs when $\epsilon_{imposed} = \epsilon_{allowed}$, the failure criterion is satisfied:

$$G_{ij}\,\epsilon_i\,\epsilon_j + G_i\,\epsilon_i = 1$$

Then strength ratio $S = 1$.

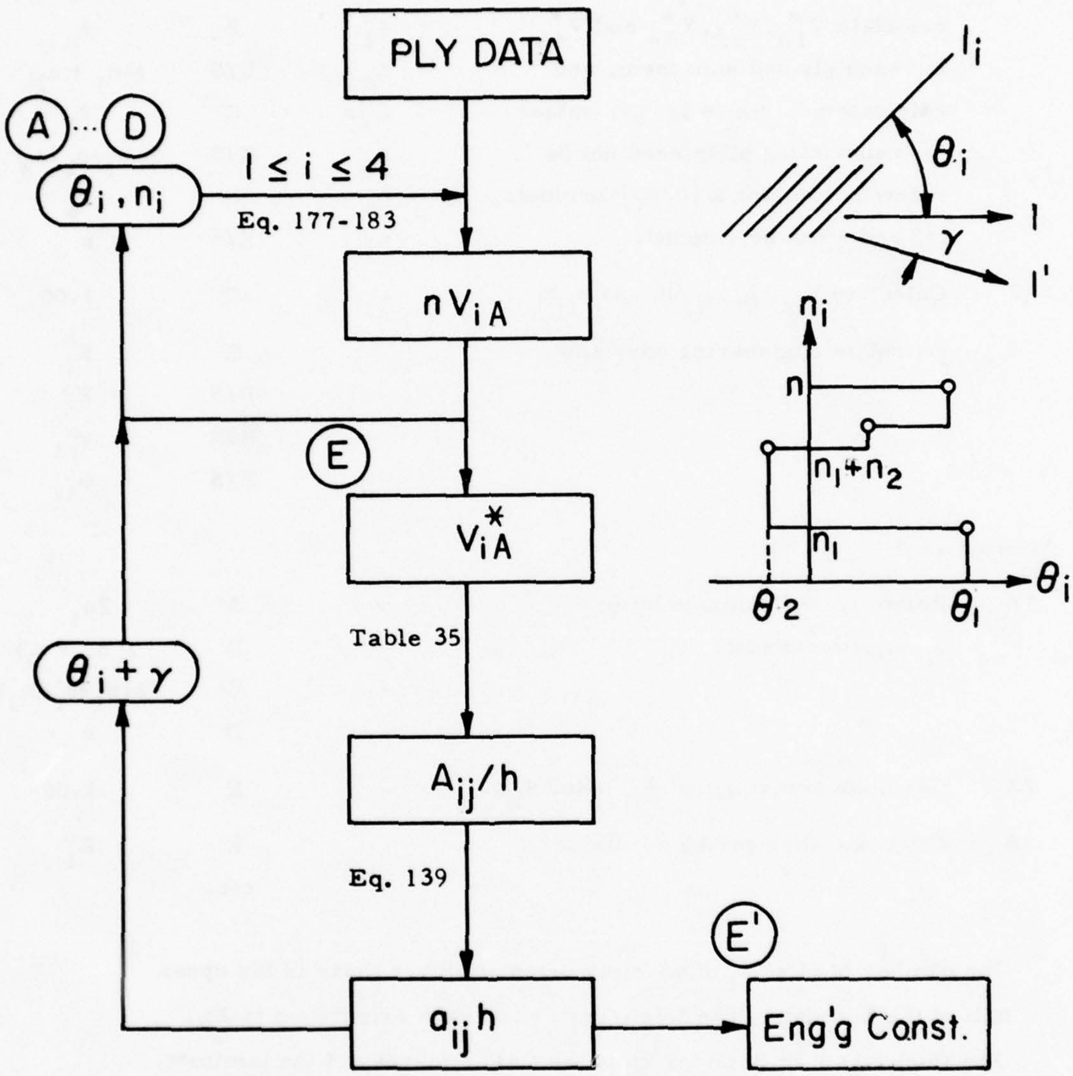
If $\epsilon_{imposed}$ is less than $\epsilon_{allowed}$, $S > 1$. The failure criterion is also satisfied:

$$G_{ij}\,\epsilon_i\,\epsilon_j\,S^2 + G_i\,\epsilon_i\,S = 1$$

where strains in this equation are $\epsilon_{imposed}$.

For a given state of imposed strains, we can solve for the quadratic equation for S; the other real root is the strength ratio S^- which corresponds to that when all the imposed strains change signs. If original ϵ_i were all positive, the S^- is the strength ratio for opposite strains, or $-\epsilon_i$.

TAPE #3
IN-PLANE STIFFNESS OF SYMMETRIC LAMINATES



USER INSTRUCTIONS

TAPE #3: IN-PLANE STIFFNESS OF SYMMETRIC LAMINATES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
0	Enter ply data.	--		
1	Enter ply angle θ_i, and number of plies at that angle, n_i^*, i=1, 4, and	θ_1	A	θ_1
		n_1	R/S	$2n_1$
	calculate V^*_{1A}, V^*_{2A}, V^*_{3A} and V^*_{4A}	θ_2	B	θ_2
	for each ply and sum them, and	n_2	R/S	$2(n_1 + n_2)$
	calculate n . Since $1 \leq i \leq 4$, values	θ_3	C	θ_3
	for nonexisting plies need not be	n_3	R/S	$2(n_1 + n_2 + n_3)$
	entered, i.e. for a [0/90] laminate,	θ_4	D	θ_4
	i=3 and 4 can be skipped.	n_4	R/S	n
2	Calculate V_{iA}, h, A_{ij}/h, and $a_{ij}h$.	--	E	1.00
3	Calculate engineering constants	--	E'	E_1^o
		--	R/S	E_2^o
		--	R/S	ν_{12}^o
		--	R/S	G_{12}^o
Alternative A				
1A	Rotate entire laminate by γ; **	γ	A'	$2n_1$
	n_i remain the same	--	B'	$2(n_1 + n_2)$
		--	C'	$2(n_1 + n_2 + n_3)$
		--	D'	n
2A	Calculate transformed A_{ij}/h and $a_{ij}h$.	--	E	1.00
3A	Calculate engineering constants	--	E'	E_1^o
		--	etc.	

* The number of plies n_i of each ply orientation are those in the upper half of the laminate. The total number for each orientation is $2n_i$. The thickness h in Register 26 is the total thickness of the laminate; the number in Register 46 is one half of the total ply number. For symmetric laminates, only the fraction of each orientation rather than the absolute number of plies is important.

** This is equivalent to rotating the reference coordinates in the clockwise or negative direction.

Tape# 3 Title IN-PLANE STIFFNESS OF SYMMETRIC LAMINATES

KEYS		STORAGE MEMORIES					
A	θ_1, n_1	0	γ	20	n_4	40	n_i
		1		21		41	h_o
A'	$\theta_1 + \gamma, n_1$	2		22		42	I_{1Q}
		3		23		43	I_{2Q}
B	θ_2, n_2	4		24		44	R_{1Q}
		5		25		45	R_{2Q}
B'	$\theta_2 + \gamma, n_2$	6		26	h	46	$n/2$
		7		27	$Q_{11}, A_{11}/h$	47	V^*_{1A}
C	θ_3, n_3	8		28	$Q_{22}, A_{22}/h$	48	V^*_{2A}
		9		29	$Q_{12}, A_{12}/h$	49	V^*_{3A}
C'	$\theta_3 + \gamma, n_3$	10		30	$Q_{66}, A_{66}/h$	50	V^*_{4A}
		11		31	A_{16}/h	51	
D	θ_4, n_4	12		32	A_{26}/h	52	
		13	θ_1	33	$a_{11}h$	53	
D'	$\theta_4 + \gamma, n_4$	14	n_1	34	$a_{22}h$	54	
		15	θ_2	35	$a_{12}h$	55	
E	$A_{ij}/h, a_{ij}h$	16	n_2	36	$a_{66}h$	56	
		17	θ_3	37	$a_{16}h$	57	
E'	Engineering Constants	18	n_3	38	$a_{26}h$	58	
		19	θ_4	39	$\theta_i, \lvert A \rvert$	59	

Tape #3 In-Plane Stiffness

Label	Step	Code	Key
θ_1, n_1	000	76	LBL
	001	11	A
	002	57	ENG
	003	42	STO
	004	13	13
	005	00	0
	006	42	STO
	007	46	46
	008	42	STO
	009	47	47
	010	42	STO
	011	48	48
	012	42	STO
	013	49	49
	014	42	STO
	015	50	50
	016	43	RCL
	017	13	13
	018	91	R/S
	019	42	STO
	020	14	14
	021	42	STO
	022	40	40
	023	44	SUM
	024	46	46
	025	43	RCL
	026	13	13
	027	71	SBR
	028	33	X²
θ_2, n_2	029	76	LBL
	030	12	B
	031	42	STO
	032	15	15
	033	91	R/S
	034	42	STO
	035	16	16
	036	42	STO
	037	40	40
	038	44	SUM
	039	46	46
	040	43	RCL
	041	15	15
	042	71	SBR
	043	33	X²
θ_3, n_3	044	76	LBL
	045	13	C
	046	42	STO
	047	17	17
	048	91	R/S
	049	42	STO
	050	18	18
	051	42	STO
	052	40	40
	053	44	SUM
	054	46	46
	055	43	RCL
	056	17	17
	057	71	SBR
	058	33	X²
θ_4, n_4	059	76	LBL
	060	14	D
	061	42	STO
	062	19	19
	063	91	R/S
	064	42	STO
	065	20	20
	066	42	STO
	067	40	40
	068	44	SUM
	069	46	46
	070	43	RCL
	071	19	19
V_{iA}	072	76	LBL
	073	33	X²
	074	65	×
	075	02	2
	076	95	=
	077	94	+/-
	078	42	STO
	079	39	39

Label	Step	Code	Key
	080	39	COS
	081	65	×
	082	43	RCL
	083	40	40
	084	95	=
	085	44	SUM
	086	47	47
	087	43	RCL
	088	39	39
	089	38	SIN
	090	65	×
	091	43	RCL
	092	40	40
	093	95	=
	094	44	SUM
	095	49	49
	096	02	2
	097	49	PRD
	098	39	39
	099	43	RCL
	100	39	39
	101	39	COS
	102	65	×
	103	43	RCL
	104	40	40
	105	95	=
	106	44	SUM
	107	48	48
	108	43	RCL
	109	39	39
	110	38	SIN
	111	65	×
	112	43	RCL
	113	40	40
	114	95	=
	115	44	SUM
	116	50	50
	117	43	RCL
	118	46	46
	119	65	×
	120	02	2
	121	95	=
	122	91	R/S
V^*_{iA}	123	76	LBL
	124	15	E
	125	01	1
	126	03	3
	127	66	PAU
	128	43	RCL
	129	46	46
	130	35	1/X
	131	49	PRD
	132	47	47
	133	49	PRD
	134	48	48
	135	49	PRD
	136	49	49
	137	49	PRD
	138	50	50
	139	35	1/X
	140	65	×
	141	43	RCL
	142	41	41
	143	65	×
	144	02	2
	145	95	=
	146	42	STO
	147	26	26
A_{ij}/h	148	43	RCL
	149	42	42
	150	85	+
	151	43	RCL
	152	43	43
	153	85	+
	154	43	RCL
	155	47	47
	156	65	×
	157	43	RCL
	158	44	44
	159	85	+

Label	Step	Code	Key
	160	43	RCL
	161	48	48
	162	65	×
	163	43	RCL
	164	45	45
	165	95	=
	166	42	STO
	167	27	27
	168	75	-
	169	02	2
	170	65	×
	171	43	RCL
	172	47	47
	173	65	×
	174	43	RCL
	175	44	44
	176	95	=
	177	42	STO
	178	28	28
	179	43	RCL
	180	42	42
	181	75	-
	182	43	RCL
	183	43	43
	184	75	-
	185	43	RCL
	186	48	48
	187	65	×
	188	43	RCL
	189	45	45
	190	95	=
	191	42	STO
	192	29	29
	193	75	-
	194	43	RCL
	195	42	42
	196	85	+
	197	02	2
	198	65	×
	199	43	RCL
	200	43	43
	201	95	=
	202	42	STO
	203	30	30
	204	43	RCL
	205	49	49
	206	65	×
	207	43	RCL
	208	44	44
	209	55	÷
	210	02	2
	211	85	+
	212	43	RCL
	213	50	50
	214	65	×
	215	43	RCL
	216	45	45
	217	95	=
	218	94	+/-
	219	42	STO
	220	31	31
	221	85	+
	222	02	2
	223	65	×
	224	43	RCL
	225	50	50
	226	65	×
	227	43	RCL
	228	45	45
	229	95	=
	230	42	STO
	231	32	32
$\lvert A \rvert$	232	43	RCL
	233	27	27
	234	65	×
	235	43	RCL
	236	28	28
	237	65	×
	238	43	RCL
	239	30	30

Tape #3 In-Plane Stiffness

	240	85	+
	241	43	RCL
	242	29	29
	243	65	×
	244	43	RCL
	245	31	31
	246	65	×
	247	43	RCL
	248	32	32
	249	65	×
	250	02	2
	251	75	-
	252	43	RCL
	253	28	28
	254	65	×
	255	43	RCL
	256	31	31
	257	33	X²
	258	75	-
	259	43	RCL
	260	27	27
	261	65	×
	262	43	RCL
	263	32	32
	264	33	X²
	265	75	-
	266	43	RCL
	267	30	30
	268	65	×
	269	43	RCL
	270	29	29
	271	33	X²
	272	95	=
	273	42	STO
	274	39	39
a^*_{ij}	275	43	RCL
	276	28	28
	277	65	×
	278	43	RCL
	279	30	30
	280	75	-
	281	43	RCL
	282	32	32
	283	33	X²
	284	95	=
	285	42	STO
	286	33	33
	287	43	RCL
	288	27	27
	289	65	×
	290	43	RCL
	291	28	28
	292	75	-
	293	43	RCL
	294	29	29
	295	33	X²
	296	95	=
	297	42	STO
	298	36	36
	299	43	RCL
	300	27	27
	301	65	×
	302	43	RCL
	303	30	30
	304	75	-
	305	43	RCL
	306	31	31
	307	33	X²
	308	95	=
	309	42	STO
	310	34	34
	311	43	RCL
	312	29	29
	313	65	×
	314	43	RCL
	315	32	32
	316	75	-
	317	43	RCL
	318	28	28
	319	65	×

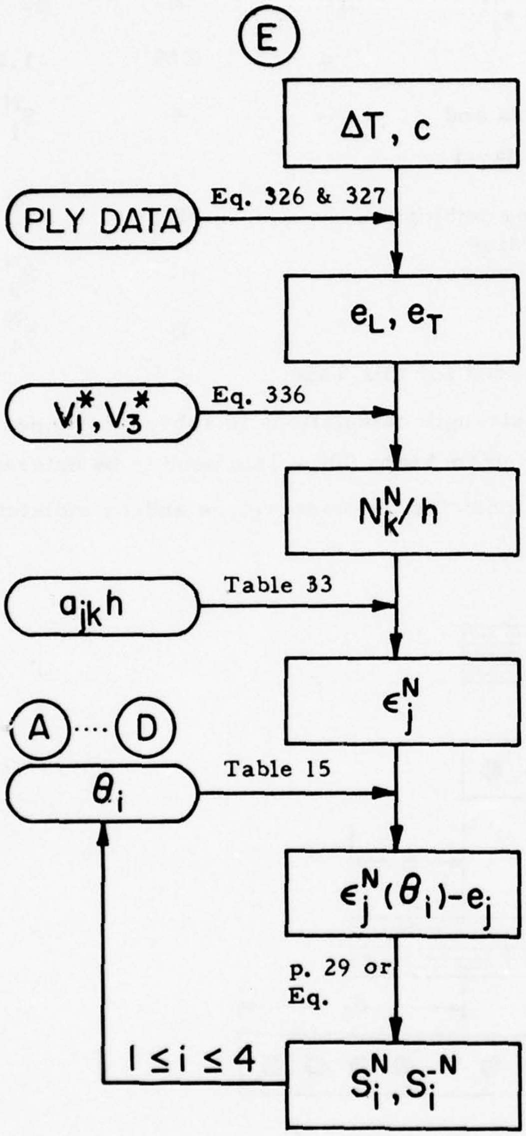
	320	43	RCL
	321	31	31
	322	95	=
	323	42	STO
	324	37	37
	325	43	RCL
	326	31	31
	327	65	×
	328	43	RCL
	329	32	32
	330	75	-
	331	43	RCL
	332	29	29
	333	65	×
	334	43	RCL
	335	30	30
	336	95	=
	337	42	STO
	338	35	35
	339	43	RCL
	340	29	29
	341	65	×
	342	43	RCL
	343	31	31
	344	75	-
	345	43	RCL
	346	27	27
	347	65	×
	348	43	RCL
	349	32	32
	350	95	=
	351	42	STO
	352	38	38
$a_{ij}h$	353	43	RCL
	354	39	39
	355	35	1/X
	356	49	PRD
	357	33	33
	358	49	PRD
	359	34	34
	360	49	PRD
	361	35	35
	362	49	PRD
	363	36	36
	364	49	PRD
	365	37	37
	366	49	PRD
	367	38	38
	368	01	1
	369	95	=
	370	91	R/S
Eng'g Const.	371	76	LBL
	372	10	E'
	373	43	RCL
	374	33	33
	375	35	1/X
	376	91	R/S
	377	43	RCL
	378	34	34
	379	35	1/X
	380	91	R/S
	381	43	RCL
	382	35	35
	383	55	÷
	384	43	RCL
	385	33	33
	386	95	=
	387	94	+/-
	388	91	R/S
	389	43	RCL
	390	36	36
	391	35	1/X
	392	91	R/S
$\theta_1+\gamma$	393	76	LBL
	394	16	A'
	395	42	STO
	396	00	00
	397	44	SUM
	398	13	13
	399	44	SUM

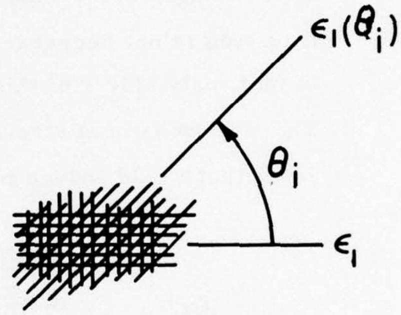
	400	15	15
	401	44	SUM
	402	17	17
	403	44	SUM
	404	19	19
	405	00	0
	406	42	STO
	407	46	46
	408	42	STO
	409	47	47
	410	42	STO
	411	48	48
	412	42	STO
	413	49	49
	414	42	STO
	415	50	50
	416	43	RCL
	417	14	14
	418	42	STO
	419	40	40
	420	44	SUM
	421	46	46
	422	43	RCL
	423	13	13
	424	71	SBR
	425	33	X²
$\theta_2+\gamma$	426	76	LBL
	427	17	B'
	428	43	RCL
	429	16	16
	430	42	STO
	431	40	40
	432	44	SUM
	433	46	46
	434	43	RCL
	435	15	15
	436	71	SBR
	437	33	X²
$\theta_3+\gamma$	438	76	LBL
	439	18	C'
	440	43	RCL
	441	18	18
	442	42	STO
	443	40	40
	444	44	SUM
	445	46	46
	446	43	RCL
	447	17	17
	448	71	SBR
	449	33	X²
$\theta_4+\gamma$	450	76	LBL
	451	19	D'
	452	43	RCL
	453	20	20
	454	42	STO
	455	40	40
	456	44	SUM
	457	46	46
	458	43	RCL
	459	19	19
	460	71	SBR
	461	33	X²
	462	00	0
	463	00	0
	464	00	0
	465	00	0
	466	00	0
	467	00	0
	468	00	0
	469	00	0
	470	00	0
	471	00	0
	472	00	0
	473	00	0
	474	00	0
	475	00	0
	476	00	0
	477	00	0
	478	00	0
	479	00	0

Tape #3 In-Plane Stiffness/Sample Problems

	0. 00	00	0. 00	00	0. 00	00	0. 00	00
	181.81114 09	01	181.81114 09	01	181.81114 09	01	181.81114 09	01
	10.346159 09	02	10.346159 09	02	10.346159 09	02	10.346159 09	02
	2.8969244 09	03	2.8969244 09	03	2.8969244 09	03	2.8969244 09	03
	0. 00	04	0. 00	04	0. 00	04	0. 00	04
	0. 00	05	0. 00	05	0. 00	05	0. 00	05
	0. 00	06	0. 00	06	0. 00	06	0. 00	06
	0. 00	07	0. 00	07	0. 00	07	0. 00	07
	0. 00	08	0. 00	08	0. 00	08	0. 00	08
	0. 00	09	0. 00	09	0. 00	09	0. 00	09
	0. 00	10	0. 00	10	0. 00	10	0. 00	10
	0. 00	11	0. 00	11	0. 00	11	0. 00	11
	0. 00	12	0. 00	12	0. 00	12	0. 00	12
θ_i	0. 00	13	45. 00	13	0. 00	13	0. 00	13
	1. 00	14	1. 00	14	1. 00	14	1. 00	14
n_i	90. 00	15	-45. 00	15	60. 00	15	90. 00	15
	1. 00	16	1. 00	16	1. 00	16	1. 00	16
	68. 06	17	68. 06	17	-60. 00	17	45. 00	17
	181. 09	18	181. 09	18	1. 00	18	1. 00	18
	10.3 09	19	10.3 09	19	10.3 09	19	-45. 00	19
	280. -03	20	280. -03	20	280. -03	20	1. 00	20
	7.17 09	21	7.17 09	21	7.17 09	21	7.17 09	21
	10. -09	22	10. -09	22	10. -09	22	10. -09	22
	12.5-06	23	12.5-06	23	12.5-06	23	12.5-06	23
	0. 00	24	0. 00	24	0. 00	24	0. 00	24
	600. -03	25	600. -03	25	600. -03	25	600. -03	25
h	500. -06	26	500. -06	26	750. -06	26	1. -03	26
	96.078649 09	27	56.657787 09	27	76.368218 09	27	76.368218 09	27
	96.078649 09	28	56.657787 09	28	76.368218 09	28	76.368218 09	28
A_{ij}/h	2.8969244 09	29	42.317787 09	29	22.607356 09	29	22.607356 09	29
	7.17 09	30	46.590862 09	30	26.880431 09	30	26.880431 09	30
	0. 00	31	0. 00	31	0. 00	31	0. 00	31
	0. 00	32	0. 00	32	0. 00	32	0. 00	32
	10.417611-12	33	39.919255-12	33	14.352198-12	33	14.352198-12	33
	10.417611-12	34	39.919255-12	34	14.352198-12	34	14.352198-12	34
$a_{ij}h$	-314.10757-15	35	-29.815752-12	35	-4.2486946-12	35	-4.2486946-12	35
	139.47001-12	36	21.463436-12	36	37.201784-12	36	37.201784-12	36
	0. 00	37	0. 00	37	0. 00	37	0. 00	37
	0. 00	38	0. 00	38	0. 00	38	0. 00	38
	66.126864 30	39	66.126864 30	39	143.0311 30	39	143.0311 30	39
	1. 00	40	1. 00	40	1. 00	40	1. 00	40
	125. -06	41	125. -06	41	125. -06	41	125. -06	41
	49.487787 09	42	49.487787 09	42	49.487787 09	42	49.487787 09	42
	26.880431 09	43	26.880431 09	43	26.880431 09	43	26.880431 09	43
	85.73249 09	44	85.73249 09	44	85.73249 09	44	85.73249 09	44
	19.710431 09	45	19.710431 09	45	19.710431 09	45	19.710431 09	45
	2. 00	46	2. 00	46	3. 00	46	4. 00	46
	0. 00	47	0. 00	47	433.33333-15	47	0. 00	47
	1. 00	48	-1. 00	48	-733.33333-15	48	0. 00	48
	0. 00	49	0. 00	49	0. 00	49	0. 00	49
	0. 00	50	0. 00	50	0. 00	50	0. 00	50
	-3.3603243-18	51	-3.3603243-18	51	-3.3603243-18	51	-3.3603243-18	51
	0. 00	52	0. 00	52	0. 00	52	0. 00	52
	0. 00	53	0. 00	53	0. 00	53	0. 00	53
	12.004384 03	54	12.004384 03	54	12.004384 03	54	12.004384 03	54
	10.680652 03	55	10.680652 03	55	10.680652 03	55	10.680652 03	55
	-3.0691032 03	56	-3.0691032 03	56	-3.0691032 03	56	-3.0691032 03	56
	11.117842 03	57	11.117842 03	57	11.117842 03	57	11.117842 03	57
	60.646995 00	58	60.646995 00	58	60.646995 00	58	60.646995 00	58
	216.59641 00	59	216.59641 00	59	216.59641 00	59	216.59641 00	59

TAPE #4
IN-PLANE NON MECHANICAL STRAINS OF SYMMETRIC LAMINATES





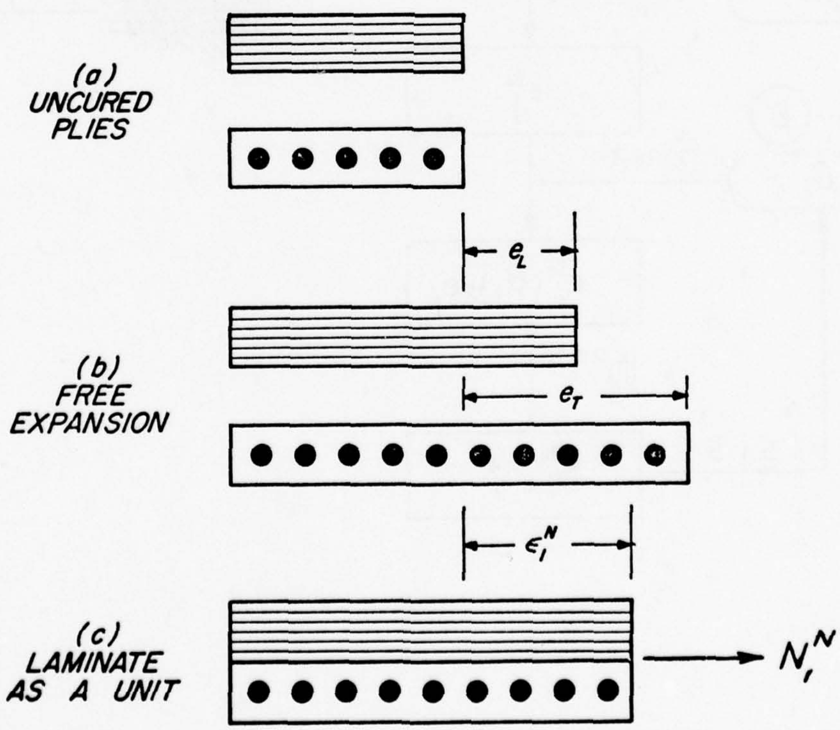
USER INSTRUCTIONS

TAPE #4: IN-PLANE NONMECHANICAL STRAINS OF SYMMETRIC LAMINATES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
0	Data from Tape #3 must be in storage.*	--		--
1	Enter ΔT, and c and calculate e_j^N	ΔT	E	ΔT
		c	R/S	1.00
2**	Calculate nonmechanical strains and the strength ratios S_i^N for each layer, i=1-4.	--	A	S_1^N
	The strengths are based on the combination of environmentally induced strains	--	B	S_2^N
	from both temperature and moisture.	--	C	S_3^N
		--	D	S_4^N

* Data in Registers 47 and 49 are needed for this Tape.

** This step is not necessary for the strength calculations in subsequent tapes. In fact, only side 1 of this tape (program steps 000 - 166) need to be entered. The nonmechanical strength ratio indicates the temperature and/or moisture level that would induce ply failures.



Tape# 4 **Title** IN-PLANE NONMECHANICAL STRAINS OF SYMMETRIC LAMINATES

KEYS		STORAGE MEMORIES					
A	S_1^N	0	γ	20	n_4	40	$q, \ldots S_i^N, S_4^N$
		1	Q_{11}	21	$2\theta_i$	41	
A'		2	Q_{22}	22	α_L^T	42	I_{1Q}
		3	Q_{12}	23	α_T^T	43	I_{2Q}
B	S_2^N	4	N_1^N/h	24	α_L^H	44	R_{1Q}
		5	N_2^N/h	25	α_T^H	45	R_{2Q}
B'		6	N_6^N/h	26	h	46	n
		7	$e_1^N(\theta_i) - e_L$	27	S_1^{-N}	47	V_{1A}^*
C	S_3^N	8	$e_2^N(\theta_i) - e_T$	28	S_2^{-N}	48	$V_{2A}^*, \Delta T$
		9	$\epsilon_6^N(\theta_i)$	29	S_3^{-N}	49	V_{3A}^*
C'		10	e_1^N	30	S_1^N	50	V_{4A}^*, c
		11	e_2^N	31	S_2^N	51	
D	S_4^N	12	e_6^N	32	S_3^N	52	e_L
		13	θ_1	33	$a_{11}\ h$	53	e_T
D'		14	n_1	34	$a_{22}\ h$	54	G_{11}
		15	θ_2	35	$a_{12}\ h$	55	G_{22}
E	$\Delta T, c$	16	n_2	36	$a_{66}\ h$	56	G_{12}
		17	θ_3	37	$a_{16}\ h$	57	G_{66}
E'		18	n_3	38	$a_{26}\ h$	58	G_1
		19	θ_4	39	$p,\ \lvert A\rvert \ldots S_4^{-N}$	59	G_2

Tape #4 In-Plane Nonmechanical

N_k^N/h

```
000  76  LBL
001  15  E
002  57  ENG
003  42  STO
004  48  48
005  91  R/S
006  42  STO
007  50  50
008  65  ×
009  43  RCL
010  24  24
011  85  +
012  43  RCL
013  48  48
014  65  ×
015  43  RCL
016  22  22
017  95  =
018  42  STO
019  52  52
020  08  8
021  66  PAU
022  43  RCL
023  48  48
024  65  ×
025  43  RCL
026  23  23
027  85  +
028  43  RCL
029  50  50
030  65  ×
031  43  RCL
032  25  25
033  95  =
034  42  STO
035  53  53
036  65  ×
037  43  RCL
038  03  03
039  85  +
040  43  RCL
041  52  52
042  65  ×
043  43  RCL
044  01  01
045  95  =
046  42  STO
047  39  39
048  43  RCL
049  52  52
050  65  ×
051  43  RCL
052  03  03
053  85  +
054  43  RCL
055  53  53
056  65  ×
057  43  RCL
058  02  02
059  95  =
060  42  STO
061  40  40
062  85  +
063  43  RCL
064  39  39
065  95  =
066  55  ÷
067  02  2
068  95  =
069  42  STO
070  39  39
071  75  -
072  43  RCL
073  40  40
074  95  =
075  42  STO
076  40  40
077  65  ×
078  43  RCL
079  47  47
080  85  +
081  43  RCL
082  39  39
083  95  =
084  42  STO
085  04  04
086  75  -
087  02  2
088  65  ×
089  43  RCL
090  47  47
091  65  ×
092  43  RCL
093  40  40
094  95  =
095  42  STO
096  05  05
097  43  RCL
098  49  49
099  65  ×
100  43  RCL
101  40  40
102  95  =
103  94  +/-
104  42  STO
105  06  06
```

ϵ_j^N

```
106  65  ×
107  43  RCL
108  37  37
109  85  +
110  43  RCL
111  04  04
112  65  ×
113  43  RCL
114  33  33
115  85  +
116  43  RCL
117  05  05
118  65  ×
119  43  RCL
120  35  35
121  95  =
122  42  STO
123  10  10
124  43  RCL
125  04  04
126  65  ×
127  43  RCL
128  35  35
129  85  +
130  43  RCL
131  05  05
132  65  ×
133  43  RCL
134  34  34
135  85  +
136  43  RCL
137  06  06
138  65  ×
139  43  RCL
140  38  38
141  95  =
142  42  STO
143  11  11
144  43  RCL
145  04  04
146  65  ×
147  43  RCL
148  37  37
149  85  +
150  43  RCL
151  05  05
152  65  ×
153  43  RCL
154  38  38
155  85  +
156  43  RCL
157  06  06
158  65  ×
159  43  RCL
160  36  36
161  95  =
162  42  STO
163  12  12
164  01  1
165  95  =
166  91  R/S
```

S_1^N

```
167  76  LBL
168  11  A
169  43  RCL
170  13  13
171  71  SBR
172  35  1/X
173  42  STO
174  27  27
175  43  RCL
176  40  40
177  42  STO
178  42  42
179  91  R/S
```

S_2^N

```
180  76  LBL
181  12  B
182  43  RCL
183  15  15
184  71  SBR
185  35  1/X
186  42  STO
187  28  28
188  43  RCL
189  40  40
190  42  STO
191  43  43
192  91  R/S
```

S_3^N

```
193  76  LBL
194  13  C
195  43  RCL
196  17  17
197  71  SBR
198  35  1/X
199  42  STO
200  29  29
201  43  RCL
202  40  40
203  42  STO
204  44  44
205  91  R/S
```

S_4^N

```
206  76  LBL
207  14  D
208  43  RCL
209  19  19
210  71  SBR
211  35  1/X
212  42  STO
213  30  30
214  43  RCL
215  40  40
216  42  STO
217  45  45
218  91  R/S
```

$\epsilon_j^N(\theta_i) - e_j$

```
219  76  LBL
220  35  1/X
221  65  ×
222  02  2
223  95  =
224  42  STO
225  21  21
226  01  1
227  00  0
228  66  PAU
229  43  RCL
230  10  10
231  85  +
232  43  RCL
233  11  11
234  95  =
235  55  ÷
236  02  2
237  95  =
238  42  STO
239  39  39
```

Tape #4 In-Plane Nonmechanical

240	75		320	65	×	400	00	0
241	43	RCL	321	43	RCL	401	00	0
242	11	11	322	07	07	402	00	0
243	95	=	323	65	×	403	00	0
244	42	STO	324	43	RCL	404	00	0
245	40	40	325	08	08	405	00	0
246	65	×	326	85	+	406	00	0
247	43	RCL	327	43	RCL	407	00	0
248	21	21	328	55	55	408	00	0
249	39	COS	329	65	×	409	00	0
250	85	+	330	43	RCL	410	00	0
251	43	RCL	331	08	08	411	00	0
252	39	39	332	33	X²	412	00	0
253	85	+	333	95	=	413	00	0
254	53	(	334	42	STO	414	00	0
255	43	RCL	335	39	39	415	00	0
256	12	12	336	43	RCL	416	00	0
257	65	×	337	58	58	417	00	0
258	43	RCL	338	65	×	418	00	0
259	21	21	339	43	RCL	419	00	0
260	38	SIN	340	07	07	420	00	0
261	54	)	341	85	+	421	00	0
262	55	÷	342	43	RCL	422	00	0
263	02	2	343	59	59	423	00	0
264	75	-	344	65	×	424	00	0
265	43	RCL	345	43	RCL	425	00	0
266	52	52	346	08	08	426	00	0
267	95	=	347	95	=	427	00	0
268	42	STO	348	55	÷	428	00	0
269	07	07	349	43	RCL	429	00	0
270	75	-	350	39	39	430	00	0
271	43	RCL	351	55	÷	431	00	0
272	10	10	352	02	2	432	00	0
273	75	-	353	95	=	433	00	0
274	43	RCL	354	42	STO	434	00	0
275	11	11	355	40	40	435	00	0
276	85	+	356	33	X²	436	00	0
277	43	RCL	357	85	+	437	00	0
278	52	52	358	43	RCL	438	00	0
279	85	+	359	39	39	439	00	0
280	43	RCL	360	35	1/X	440	00	0
281	53	53	361	95	=	441	00	0
282	95	=	362	34	ΓX	442	00	0
283	94	+/-	363	42	STO	443	00	0
284	42	STO	364	39	39	444	00	0
285	08	08	365	75	-	445	00	0
286	43	RCL	366	43	RCL	446	00	0
287	12	12	367	40	40	447	00	0
288	65	×	368	95	=	448	00	0
289	43	RCL	369	42	STO	449	00	0
290	21	21	370	40	40	450	00	0
291	39	COS	371	75	-	451	00	0
292	75	-	372	02	2	452	00	0
293	43	RCL	373	65	×	453	00	0
294	40	40	374	43	RCL	454	00	0
295	65	×	375	39	COS	455	00	0
296	02	2	376	95	=	456	00	0
297	65	×	377	94	+/-	457	00	0
298	43	RCL	378	92	RTN	458	00	0
299	21	21	379	00	0	459	00	0
300	38	SIN	380	00	0	460	00	0
301	95	=	381	00	0	461	00	0
302	42	STO	382	00	0	462	00	0
303	09	09	383	00	0	463	00	0
S_i^N 304	33	X²	384	00	0	464	00	0
305	65	×	385	00	0	465	00	0
306	43	RCL	386	00	0	466	00	0
307	57	57	387	00	0	467	00	0
308	85	+	388	00	0	468	00	0
309	43	RCL	389	00	0	469	00	0
310	54	54	390	00	0	470	00	0
311	65	×	391	00	0	471	00	0
312	43	RCL	392	00	0	472	00	0
313	07	07	393	00	0	473	00	0
314	33	X²	394	00	0	474	00	0
315	85	+	395	00	0	475	00	0
316	02	2	396	00	0	476	00	0
317	65	×	397	00	0	477	00	0
318	43	RCL	398	00	0	478	00	0
319	56	56	399	00	0	479	00	0

Tape #4 In-Plane Nonmechanical / sample problems

	0. 00	00	0. 00	00	0. 00	00
	181.81114 09	01	181.81114 09	01	181.81114 09	01
	10.346159 09	02	10.346159 09	02	10.346159 09	02
	2.8969244 09	03	2.8969244 09	03	2.8969244 09	03
	-12.553922 06	04	19.864625 06	04	7.3107032 06	04
	-12.553922 06	05	19.864625 06	05	7.3107032 06	05
	0. 00	06	0. 00	06	0. 00	06
	-125.33858-06	07	200.7023-06	07	75.363712-06	07
	1.7481614-03	08	-2.7992977-03	08	-1.0511363-03	08
	0. 00	09	0. 00	09	0. 00	09
	-126.83858-06	10	200.7023-06	10	73.863712-06	10
	-126.83858-06	11	200.7023-06	11	73.863712-06	11
	0. 00	12	0. 00	12	0. 00	12
	0. 00	13	0. 00	13	0. 00	13
	1. 00	14	1. 00	14	1. 00	14
	90. 00	15	90. 00	15	90. 00	15
	1. 00	16	1. 00	16	1. 00	16
	68. 06	17	68. 06	17	68. 06	17
	181. 09	18	181. 09	18	181. 09	18
	10.3 09	19	10.3 09	19	10.3 09	19
	280. -03	20	280. -03	20	280. -03	20
	180. 00	21	180. 00	21	180. 00	21
	10. -09	22	10. -09	22	10. -09	22
	12.5-06	23	12.5-06	23	12.5-06	23
	0. 00	24	0. 00	24	0. 00	24
	600. -03	25	600. -03	25	600. -03	25
	500. -06	26	500. -06	26	500. -06	26
	13.092402 00	27	1.395767 00	27	3.7170891 00	27
	13.092402 00	28	1.395767 00	28	3.7170891 00	28
	2.8969244 09	29	2.8969244 09	29	2.8969244 09	29
	2.2350152 00	30	8.1762053 00	30	21.774182 00	30
	2.2350152 00	31	8.1762053 00	31	21.774182 00	31
	0. 00	32	0. 00	32	0. 00	32
	10.417611-12	33	10.417611-12	33	10.417611-12	33
	10.417611-12	34	10.417611-12	34	10.417611-12	34
	-314.10757-15	35	-314.10757-15	35	-314.10757-15	35
	139.47001-12	36	139.47001-12	36	139.47001-12	36
	0. 00	37	0. 00	37	0. 00	37
	0. 00	38	0. 00	38	0. 00	38
	7.6637088 00	39	4.7859861 00	39	12.745636 00	39
	2.2350152 00	40	8.1762053 00	40	21.774182 00	40
	125. -06	41	125. -06	41	125. -06	41
	49.487787 09	42	49.487787 09	42	49.487787 09	42
	26.880431 09	43	26.880431 09	43	26.880431 09	43
	85.73249 09	44	85.73249 09	44	85.73249 09	44
	19.710431 09	45	19.710431 09	45	19.710431 09	45
	2. 00	46	2. 00	46	2. 00	46
	0. 00	47	0. 00	47	0. 00	47
ΔT	-150. 00	48	0. 00	48	-150. 00	48
	0. 00	49	0. 00	49	0. 00	49
C	0. 00	50	5. -03	50	5. -03	50
	-3.3603243-18	51	-3.3603243-18	51	-3.3603243-18	51
	-1.5-06	52	0. 00	52	-1.5-06	52
	-1.875-03	53	3. -03	53	1.125-03	53
	12.004384 03	54	12.004384 03	54	12.004384 03	54
	10.680652 03	55	10.680652 03	55	10.680652 03	55
	-3.0691032 03	56	-3.0691032 03	56	-3.0691032 03	56
	11.117842 03	57	11.117842 03	57	11.117842 03	57
	60.646995 00	58	60.646995 00	58	60.646995 00	58
	216.59641 00	59	216.59641 00	59	216.59641 00	59

TAPE #4

STRENGTH RATIOS FOR NONMECHANICAL STRAINS OF LAMINATES

Define $S^N = \left.\dfrac{e_{allowed}}{e_{imposed}}\right]^N$

The strains that must satisfy the failure criterion are

$$e_i\Big]^N_{allowed} = \Big[e_i^N - e_i\Big]_{all.} = \begin{Bmatrix} e_1^N - e_L \\ e_2^N - e_T \\ e_6^N \end{Bmatrix}_{allowed}$$

where e_i^N = nonmechanical strains

$e_i = \{e_L, e_T, 0\}$ = longitudinal, and transverse strains induced by temperature and moisture.

Final failure criterion

$$G_{ij}(e_i^N - e_i)(e_j^N - e_j) + G_i(e_i^N - e_i) = 1$$

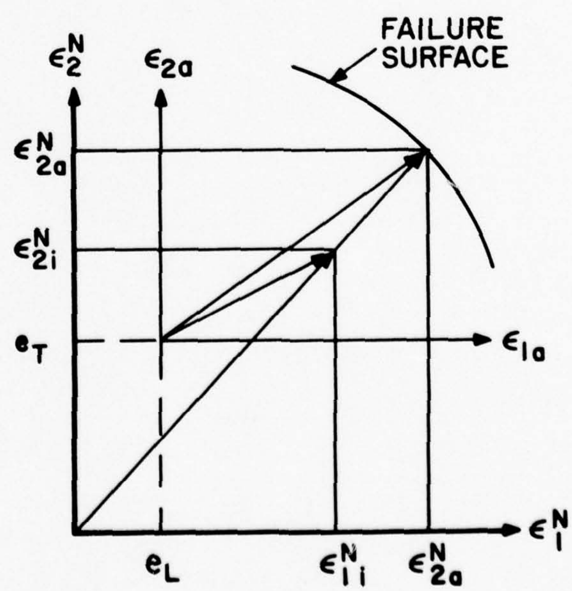
In terms of strength ratio S^N and imposed strain (nonmechanical):

$$G_{ij}\, S^N(e_i^N - e_i)\, S^N(e_j^N - e_j) + G_i\, S^N(e_i^N - e_i) = 1$$

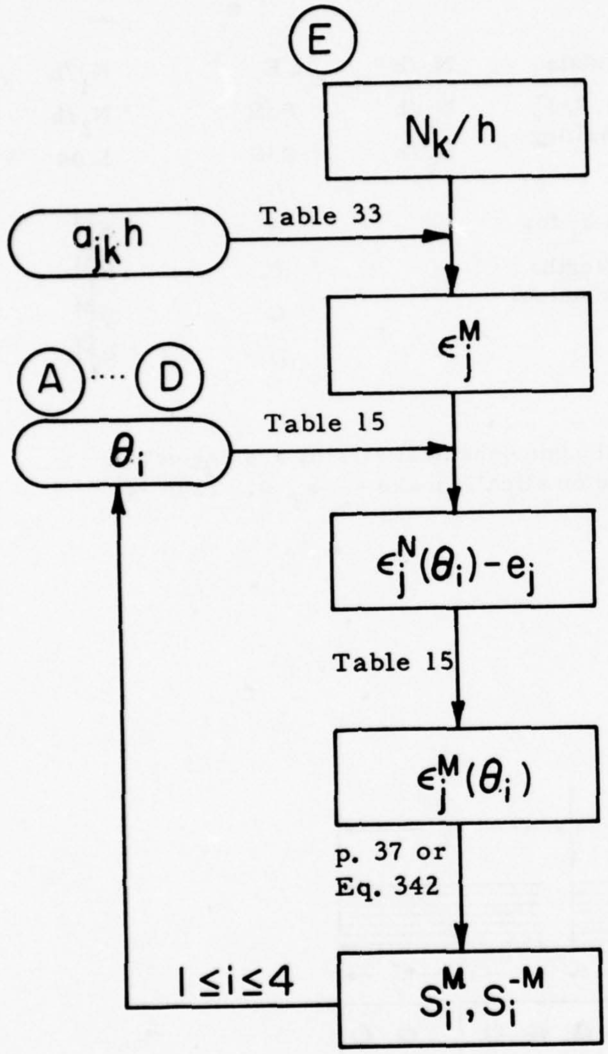
Expand this equation and solve for S^N:

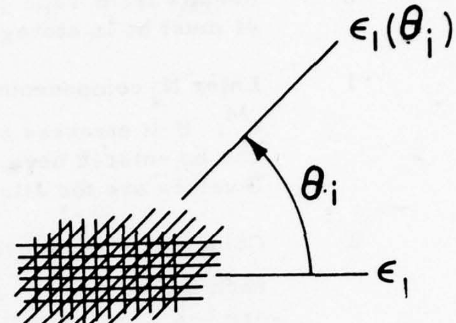
$$a(S^N)^2 + bS^N + c = 0$$

The two roots are S^N and S^{-N}.



TAPE #5
IN-PLANE STRENGTH OF SYMMETRIC LAMINATES



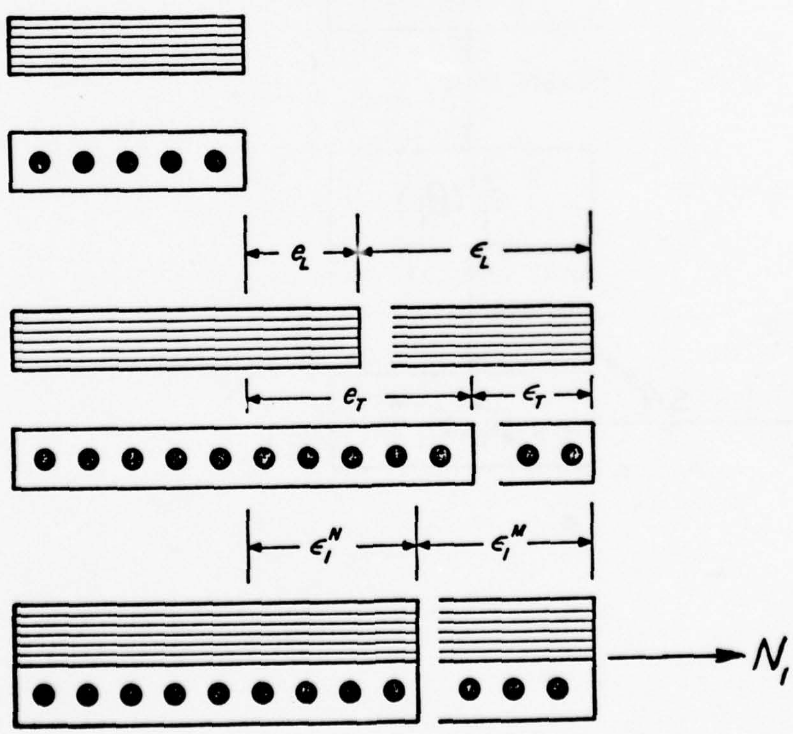


USER INSTRUCTIONS

TAPE #5: IN-PLANE STRENGTH OF SYMMETRIC LAMINATES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
0	Results from Tape #3, or #3 and #4 must be in storage*	--		--
1	Enter N_k components and calculate e_i^M. Unit stresses such as [1, 0, 0] can be entered here. The resulting S values are the allowables.	N_1/h	E	N_1/h
		N_2/h	R/S	N_2/h
		N_6/h	R/S	1.00
2	Calculate strength ratios S_i & S_i^- for each layer, i=1-4. These strengths are based on the ratios of mechanical strains; not the total strains.	--	A	S_1^M
		--	B	S_2^M
		--	C	S_3^M
		--	D	S_4^M

*Tape #5 can be used following Tape #3 if nonmechanical strains are neglected. Ply data tape used in Step 0 of Tape #3 automatically make $e_L = e_T = 0$. Tape #4 need not be run for making $\Delta T = c = 0$.



Tape* 5 Title IN-PLANE STRENGTH OF SYMMETRIC LAMINATES

KEYS	STORAGE MEMORIES					
A S_1^M	0		20		40	
	1	N_1/h	21	$2\theta_i$	41	
A'	2	N_2/h	22		42	S_1^M
	3	N_6/h	23		43	S_2^M
B S_2^M	4		24		44	S_3^M
	5		25		45	S_4^M
B'	6		26		46	
	7	ϵ_1^M	27	$\epsilon_1^M(\theta_i)$	47	S_1^{-M}
C S_3^M	8	ϵ_2^M	28	$\epsilon_2^M(\theta_i)$	48	S_2^{-M}
	9	ϵ_6^M	29	$\epsilon_6^M(\theta_i)$	49	S_3^{-M}
C'	10	ϵ_1^N	30	$\epsilon_1^N(\theta_i)-e_L$	50	S_4^{-M}
	11	ϵ_2^N	31	$\epsilon_2^N(\theta_i)-e_T$	51	
D S_4^M	12	ϵ_6^N	32	$\epsilon_6^N(\theta_i)$	52	e_L
	13	θ_1	33	$a_{11}h$	53	e_T
D'	14		34	$a_{22}h$	54	G_{11}
	15	θ_2	35	$a_{12}h$	55	G_{22}
E N_k/h, ϵ_j^M	16		36	$a_{66}h$	56	G_{12}
	17	θ_3	37	$a_{16}h$	57	G_{66}
E'	18		38	$a_{26}h$	58	G_1
	19	θ_4	39		59	G_2

Tape #5 In-Plane Strength

N_k/h

```
000  76  LBL
001  15  E
002  42  STO
003  01  01
004  91  R/S
005  42  STO
006  02  02
007  91  R/S
008  42  STO
009  03  03
```

ϵ_j^M

```
010  65  ×
011  43  RCL
012  37  37
013  85  +
014  43  RCL
015  01  01
016  65  ×
017  43  RCL
018  33  33
019  85  +
020  43  RCL
021  02  02
022  65  ×
023  43  RCL
024  35  35
025  95  =
026  42  STO
027  07  07
028  43  RCL
029  01  01
030  65  ×
031  43  RCL
032  35  35
033  85  +
034  43  RCL
035  02  02
036  65  ×
037  43  RCL
038  34  34
039  85  +
040  43  RCL
041  03  03
042  65  ×
043  43  RCL
044  38  38
045  95  =
046  42  STO
047  08  08
048  43  RCL
049  01  01
050  65  ×
051  43  RCL
052  37  37
053  85  +
054  43  RCL
055  02  02
056  65  ×
057  43  RCL
058  38  38
059  85  +
060  43  RCL
061  03  03
062  65  ×
063  43  RCL
064  36  36
065  95  =
066  42  STO
067  09  09
068  01  1
069  95  =
070  91  R/S
```

S_1^M

```
071  76  LBL
072  11  A
073  43  RCL
074  13  13
075  71  SBR
076  35  1/X
077  42  STO
078  47  47
079  43  RCL
080  40  40
081  42  STO
082  42  42
083  91  R/S
```

S_2^M

```
084  76  LBL
085  12  B
086  43  RCL
087  15  15
088  71  SBR
089  35  1/X
090  42  STO
091  48  48
092  43  RCL
093  40  40
094  42  STO
095  43  43
096  91  R/S
```

S_3^M

```
097  76  LBL
098  13  C
099  43  RCL
100  17  17
101  71  SBR
102  35  1/X
103  42  STO
104  49  49
105  43  RCL
106  40  40
107  42  STO
108  44  44
109  91  R/S
```

S_4^M

```
110  76  LBL
111  14  D
112  43  RCL
113  19  19
114  71  SBR
115  35  1/X
116  42  STO
117  50  50
118  43  RCL
119  40  40
120  42  STO
121  45  45
122  91  R/S
```

$\epsilon_j^N(\theta_i)$
$- e_j$

```
123  76  LBL
124  35  1/X
125  65  ×
126  02  2
127  95  =
128  42  STO
129  21  21
130  01  1
131  08  8
132  66  PAU
133  43  RCL
134  10  10
135  85  +
136  43  RCL
137  11  11
138  95  =
139  55  ÷
140  02  2
141  95  =
142  42  STO
143  39  39
144  75  -
145  43  RCL
146  11  11
147  95  =
148  42  STO
149  40  40
150  65  ×
151  43  RCL
152  21  21
153  39  COS
154  85  +
155  43  RCL
156  39  39
157  85  +
158  43  RCL
159  12  12
160  65  ×
161  43  RCL
162  21  21
163  38  SIN
164  55  ÷
165  02  2
166  75  -
167  43  RCL
168  52  52
169  95  =
170  42  STO
171  30  30
172  75  -
173  43  RCL
174  10  10
175  75  -
176  43  RCL
177  11  11
178  85  +
179  43  RCL
180  52  52
181  85  +
182  43  RCL
183  53  53
184  95  =
185  94  +/-
186  42  STO
187  31  31
188  43  RCL
189  12  12
190  65  ×
191  43  RCL
192  21  21
193  39  COS
194  75  -
195  43  RCL
196  40  40
197  65  ×
198  02  2
199  65  ×
200  43  RCL
201  21  21
202  38  SIN
203  95  =
204  42  STO
205  32  32
```

$\epsilon_j^M(\theta_i)$

```
206  43  RCL
207  07  07
208  85  +
209  43  RCL
210  08  08
211  95  =
212  55  ÷
213  02  2
214  95  =
215  42  STO
216  39  39
217  75  -
218  43  RCL
219  08  08
220  95  =
221  42  STO
222  40  40
223  65  ×
224  43  RCL
225  21  21
226  39  COS
227  85  +
228  43  RCL
229  39  39
230  85  +
231  43  RCL
232  09  09
233  65  ×
234  43  RCL
235  21  21
236  38  SIN
237  55  ÷
238  02  2
239  95  =
```

Tape #5 In-Plane Strength

240	42	STO
241	27	27
242	75	-
243	43	RCL
244	07	07
245	75	-
246	43	RCL
247	08	08
248	95	=
249	94	+/-
250	42	STO
251	28	28
252	43	RCL
253	09	09
254	65	×
255	43	RCL
256	21	21
257	39	COS
258	75	-
259	43	RCL
260	40	40
261	65	×
262	02	2
263	65	×
264	43	RCL
265	21	21
266	38	SIN
267	95	=
268	42	STO
269	29	29
S_i^M 270	33	X^2
271	65	×
272	43	RCL
273	57	57
274	85	+
275	43	RCL
276	54	54
277	65	×
278	43	RCL
279	27	27
280	33	X^2
281	85	+
282	02	2
283	65	×
284	43	RCL
285	56	56
286	65	×
287	43	RCL
288	27	27
289	65	×
290	43	RCL
291	28	28
292	85	+
293	43	RCL
294	55	55
295	65	×
296	43	RCL
297	28	28
298	33	X^2
299	95	=
300	42	STO
301	39	39
302	43	RCL
303	58	58
304	65	×
305	43	RCL
306	27	27
307	85	+
308	43	RCL
309	59	59
310	65	×
311	43	RCL
312	28	28
313	85	+
314	02	2
315	65	×
316	53	(
317	43	RCL
318	54	54
319	65	×
320	43	RCL
321	27	27
322	65	×
323	43	RCL
324	30	30
325	85	+
326	43	RCL
327	56	56
328	65	×
329	53	(
330	43	RCL
331	27	27
332	65	×
333	43	RCL
334	31	31
335	85	+
336	43	RCL
337	28	28
338	65	×
339	43	RCL
340	30	30
341	54	)
342	85	+
343	43	RCL
344	55	55
345	65	×
346	43	RCL
347	28	28
348	65	×
349	43	RCL
350	31	31
351	85	+
352	43	RCL
353	57	57
354	65	×
355	43	RCL
356	29	29
357	65	×
358	43	RCL
359	32	32
360	95	=
361	55	÷
362	43	RCL
363	39	39
364	55	÷
365	02	2
366	95	=
367	42	STO
368	40	40
369	01	1
370	75	-
371	43	RCL
372	54	54
373	65	×
374	43	RCL
375	30	30
376	33	X^2
377	75	-
378	02	2
379	65	×
380	43	RCL
381	56	56
382	65	×
383	43	RCL
384	30	30
385	65	×
386	43	RCL
387	31	31
388	75	-
389	43	RCL
390	55	55
391	65	×
392	43	RCL
393	31	31
394	33	X^2
395	75	-
396	43	RCL
397	57	57
398	65	×
399	43	RCL
400	32	32
401	33	X^2
402	75	-
403	43	RCL
404	58	58
405	65	×
406	43	RCL
407	30	30
408	75	-
409	43	RCL
410	59	59
411	65	×
412	43	RCL
413	31	31
414	95	=
415	55	÷
416	43	RCL
417	39	39
418	85	+
419	43	RCL
420	40	40
421	33	X^2
422	95	=
423	34	$\sqrt{X}$
424	42	STO
425	39	39
426	75	-
427	43	RCL
428	40	40
429	95	=
430	42	STO
431	40	40
432	75	-
433	02	2
434	65	×
435	43	RCL
436	39	39
437	95	=
438	94	+/-
439	92	RTN
440	00	0
441	00	0
442	00	0
443	00	0
444	00	0
445	00	0
446	00	0
447	00	0
448	00	0
449	00	0
450	00	0
451	00	0
452	00	0
453	00	0
454	00	0
455	00	0
456	00	0
457	00	0
458	00	0
459	00	0
460	00	0
461	00	0
462	00	0
463	00	0
464	00	0
465	00	0
466	00	0
467	00	0
468	00	0
469	00	0
470	00	0
471	00	0
472	00	0
473	00	0
474	00	0
475	00	0
476	00	0
477	00	0
478	00	0
479	00	0

Tape #5 In-Plane Strength/Sample Problems

	0. 00	0. 00	0. 00	0. 00	00
N_K	1. 00	1. 00	1. 00	1. 00	01
	0. 00	0. 00	0. 00	0. 00	02
	0. 00	0. 00	0. 00	0. 00	03
	7.3107032 06	0. 00	-111.69921 00	0. 00	04
	7.3107032 06	0. 00	111.69921 00	0. 00	05
	0. 00	0. 00	0. 00	0. 00	06
	10.417611-12	10.417611-12	39.919255-12	39.919255-12	07
	-314.10757-15	-314.10757-15	-29.815752-12	-29.815752-12	08
	0. 00	0. 00	0. 00	0. 00	09
	73.863712-06	0. 00	-7.7893455-09	0. 00	10
	73.863712-06	0. 00	7.7893455-09	0. 00	11
	0. 00	0. 00	0. 00	0. 00	12
θ_i	0. 00	0. 00	45. 00	45. 00	13
	1. 00	1. 00	1. 00	1. 00	14
n_i	90. 00	90. 00	-45. 00	-45. 00	15
	1. 00	1. 00	1. 00	1. 00	16
	68. 06	68. 06	68. 06	68. 06	17
	181. 09	181. 09	181. 09	181. 09	18
	10.3 09	10.3 09	10.3 09	10.3 09	19
	280. -03	280. -03	280. -03	280. -03	20
	180. 00	180. 00	-90. 00	-90. 00	21
	10. -09	10. -09	10. -09	10. -09	22
	12.5-06	12.5-06	12.5-06	12.5-06	23
	0. 00	0. 00	0. 00	0. 00	24
	600. -03	600. -03	600. -03	600. -03	25
	500. -06	500. -06	500. -06	500. -06	26
	-314.10757-15	-314.10757-15	5.0517515-12	5.0517515-12	27
	10.417611-12	10.417611-12	5.0517515-12	5.0517515-12	28
	0. 00	0. 00	69.735007-12	69.735007-12	29
	75.363712-06	0. 00	1.5-06	0. 00	30
	-1.0511363-03	0. 00	-1.125-03	0. 00	31
	0. 00	0. 00	-15.578691-09	0. 00	32
	10.417611-12	10.417611-12	39.919255-12	39.919255-12	33
	10.417611-12	10.417611-12	39.919255-12	39.919255-12	34
	-314.10757-15	-314.10757-15	-29.815752-12	-29.815752-12	35
	139.47001-12	139.47001-12	21.463436-12	21.463436-12	36
	0. 00	0. 00	0. 00	0. 00	37
	0. 00	0. 00	0. 00	0. 00	38
	1.3193015 09	1.3211072 09	150.73203 06	136.08024 06	39
	473.81212 06	373.39552 06	138.67287 06	123.2282 06	40
	125. -06	125. -06	125. -06	125. -06	41
S_i^M	739.83225 06	681.88201 06	138.67287 06	123.2282 06	42
	473.81212 06	373.39552 06	138.67287 06	123.2282 06	43
	85.73249 09	85.73249 09	85.73249 09	85.73249 09	44
	19.710431 09	19.710431 09	19.710431 09	19.710431 09	45
	2. 00	2. 00	2. 00	2. 00	46
S_i^{-M}	1.2360994 09	1.1077053 09	162.79119 06	148.93229 06	47
	2.1647909 09	2.2688189 09	162.79119 06	148.93229 06	48
	0. 00	0. 00	0. 00	0. 00	49
	5. -03	0. 00	5. -03	0. 00	50
	-3.3603243-18	-3.3603243-18	-3.3603243-18	-3.3603243-18	51
	-1.5-06	0. 00	-1.5-06	0. 00	52
	1.125-03	0. 00	1.125-03	0. 00	53
	12.004384 03	12.004384 03	12.004384 03	12.004384 03	54
	10.680652 03	10.680652 03	10.680652 03	10.680652 03	55
	-3.0691032 03	-3.0691032 03	-3.0691032 03	-3.0691032 03	56
	11.117842 03	11.117842 03	11.117842 03	11.117842 03	57
	60.646995 00	60.646995 00	60.646995 00	60.646995 00	58
	216.59641 00	216.59641 00	216.59641 00	216.59641 00	59

STRENGTH RATIOS FOR MECHANICAL STRAINS OF LAMINATES

Define $$S^M = \frac{e^M_{allowed}}{e^M_{imposed}}$$

The strains that must satisfy the failure criterion are:

$$e_i\Big]_{allowed} = e_i^M\Big]_{allowed} + e_i^N - e_i$$

$$= \begin{Bmatrix} e_1^M + e_1^N - e_L \\ e_2^M + e_2^N - e_T \\ e_6^M + e_6^N \end{Bmatrix}$$

Final failure criterion

$$G_{ij}(e^M_{ia} + e_i^N - e_i)(e^M_{ja} + e_j^N - e_j) + G_i(e^M_{ia} + e_i^N - e_i) = 1$$

In terms of safety factor S^M, and $e^M_{imposed}$

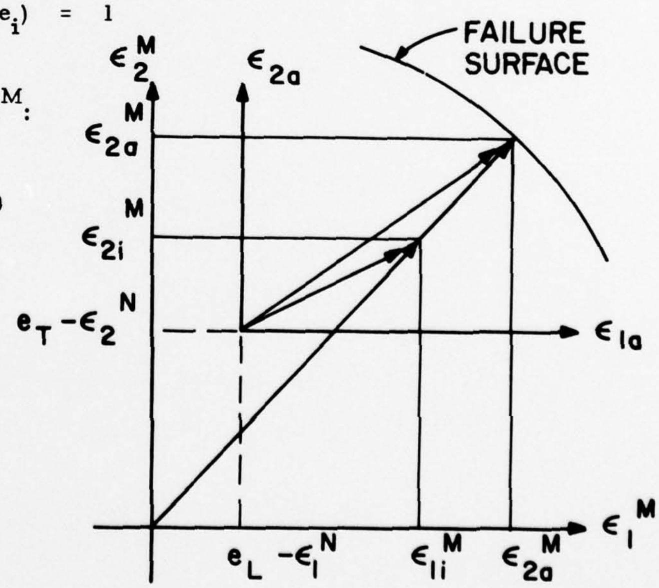
$$G_{ij}(S^M e_i^M + e_i^N - e_i)(S^M e_j^M + e_j^N - e_j)$$

$$+ G_i(S^M e_i^M + e_i^N - e_i) = 1$$

Expand this equation and solve for S^M:

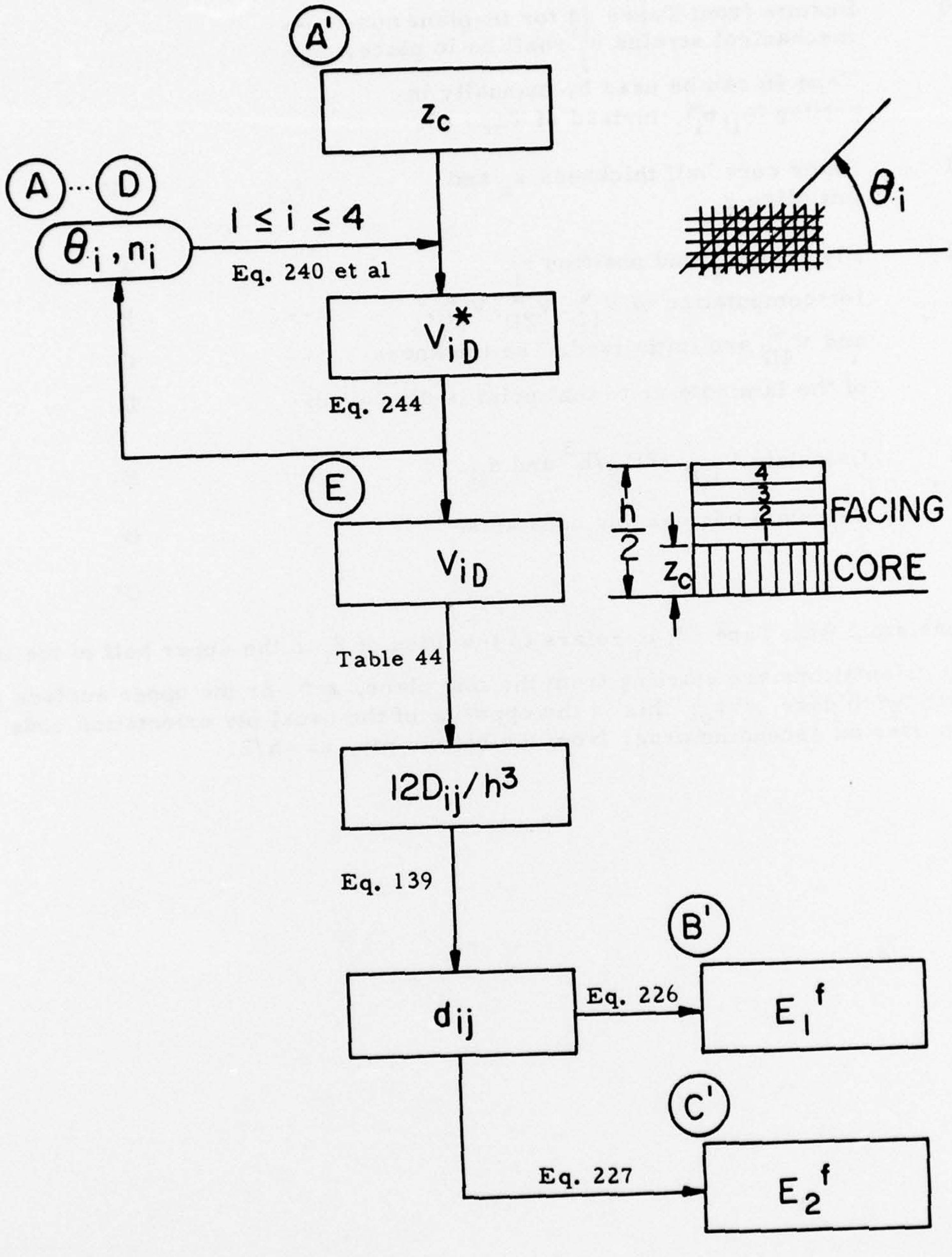
$$a(S^M)^2 + bS^M + c = 0$$

The two roots are S^M and S^{-M}.



TAPE #6

FLEXURAL RIGIDITY OF SYMMETRIC SANDWICH PLATES



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USER INSTRUCTIONS

TAPE #6: FLEXURAL RIGIDITY OF SYMMETRIC SANDWICH PLATES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
0	Results from Tapes #4 for in-plane non-mechanical strains e_j^N shall be in place.	--	--	--
	Tape #6 can be used by manually inputting (θ_i, n_i^*), instead of Tape #3.			
1	Enter core half thickness z_c and initialize z_i	z_c	A'	0.00
2	Ply angle θ_i^{**} and position z_i	--	A	$2z_1$
	for computation of V_{1D}^*, V_{2D}^*, V_{3D}^*,	--	B	$2z_2$
	and V_{4D}^* are initialized. The thickness	--	C	$2z_3$
	of the laminate up to that point is displayed.	--	D	$2z_4$
3	Calculate V_{iD}, $12D_{ij}/h^3$ and d_{ij}.	--	E	1.00
4	Calculate engineering constants		B'	E_1^f
			C'	E_2^f

* Consistent with Tape #3, n_i refers to the plies of θ_i in the upper half of the laminate.

** Ply orientations are starting from the mid plane, z=0, or the upper surface of the sandwich core, $z=z_c$; this is the opposite of the usual ply orientation code which uses an ascending order from the bottom ply, $z= -h/2$.

Tape# 6 Title FLEXURAL RIGIDITY OF SYMMETRIC SANDWICH PLATES

KEYS	STORAGE MEMORIES		
A θ_1	0	20 $n_4, z_4 = \frac{h}{2}$	40
	1	21 z_c	41 h_o
A' z_c, z_i	2	22 V_{1D}	42 I_{1Q}
	3	23 V_{2D}	43 I_{2Q}
B θ_2	4	24 V_{3D}	44 R_{1Q}
	5	25 V_{4D}	45 R_{2Q}
B' E_1^f	6	26	46 $1-\left(\frac{2z_c}{h}\right)^3$
	7	27 $12D_{11}/h^3$	47
C θ_3	8	28 $12D_{22}/h^3$	48
	9	29 $12D_{12}/h^3$	49 $2\theta_i$
C' E_2^f	10 e_1^N	30 $12D_{66}/h^3$	50 $z_i^3 - z_{i-1}^3$
	11 e_2^N	31 $12D_{16}/h^3$	51 $h/2,\ h^3/12$
D θ_4	12 e_6^N	32 $12D_{26}/h^3$	52 e_L
	13 θ_1	33 d_{11}	53 e_T
D'	14 n_1, z_1	34 d_{22}	54 G_{11}
	15 θ_2	35 d_{12}	55 G_{22}
E $12D_{ij}/h^3, d_{ij}$	16 n_2, z_2	36 d_{66}	56 G_{12}
	17 θ_3	37 d_{16}	57 G_{66}
E'	18 n_3, z_3	38 d_{26}	58 G_1
	19 θ_4	39 $\|D\|$	59 G_2

Tape #6 Flexural Rigidity

z_i

```
000  76 LBL
001  16 A'
002  42 STO
003  21  21
004  85  +
005  43 RCL
006  14  14
007  65  x
008  43 RCL
009  41  41
010  95  =
011  42 STO
012  14  14
013  85  +
014  43 RCL
015  16  16
016  65  x
017  43 RCL
018  41  41
019  95  =
020  42 STO
021  16  16
022  85  +
023  43 RCL
024  18  18
025  65  x
026  43 RCL
027  41  41
028  95  =
029  42 STO
030  18  18
031  85  +
032  43 RCL
033  20  20
034  65  x
035  43 RCL
036  41  41
037  95  =
038  42 STO
039  20  20
040  00  0
041  42 STO
042  22  22
043  42 STO
044  23  23
045  42 STO
046  24  24
047  42 STO
048  25  25
049  91 R/S
```

z_1

```
050  76 LBL
051  11  A
052  43 RCL
053  14  14
054  42 STO
055  51  51
056  45 Y^X
057  03  3
058  75  -
059  43 RCL
060  21  21
061  45 Y^X
062  03  3
063  95  =
064  42 STO
065  50  50
066  43 RCL
067  13  13
068  71 SBR
069  33 X^2
```

z_2

```
070  76 LBL
071  12  B
072  43 RCL
073  16  16
074  42 STO
075  51  51
076  45 Y^X
077  03  3
078  75  -
079  43 RCL
080  14  14
081  45 Y^X
082  03  3
083  95  =
084  42 STO
085  50  50
086  43 RCL
087  15  15
088  71 SBR
089  33 X^2
```

z_3

```
090  76 LBL
091  13  C
092  43 RCL
093  18  18
094  42 STO
095  51  51
096  45 Y^X
097  03  3
098  75  -
099  43 RCL
100  16  16
101  45 Y^X
102  03  3
103  95  =
104  42 STO
105  50  50
106  43 RCL
107  17  17
108  71 SBR
109  33 X^2
```

z_4

```
110  76 LBL
111  14  D
112  43 RCL
113  20  20
114  42 STO
115  51  51
116  45 Y^X
117  03  3
118  75  -
119  43 RCL
120  18  18
121  45 Y^X
122  03  3
123  95  =
124  42 STO
125  50  50
126  43 RCL
127  19  19
```

V^*_{iD}

```
128  76 LBL
129  33 X^2
130  65  x
131  02  2
132  95  =
133  94 +/-
134  42 STO
135  49  49
136  39 COS
137  65  x
138  43 RCL
139  50  50
140  95  =
141  44 SUM
142  22  22
143  43 RCL
144  49  49
145  38 SIN
146  65  x
147  43 RCL
148  50  50
149  95  =
150  44 SUM
151  24  24
152  02  2
153  49 PRD
154  49  49
155  43 RCL
156  49  49
157  39 COS
158  65  x
159  43 RCL
160  50  50
161  95  =
162  44 SUM
163  23  23
164  43 RCL
165  49  49
166  38 SIN
167  65  x
168  43 RCL
169  50  50
170  95  =
171  44 SUM
172  25  25
173  43 RCL
174  51  51
175  65  x
176  02  2
177  95  =
178  91 R/S
```

V_{iD}

```
179  76 LBL
180  15  E
181  01  1
182  03  3
183  66 PAU
184  43 RCL
185  51  51
186  45 Y^X
187  03  3
188  95  =
189  35 1/X
190  49 PRD
191  22  22
192  49 PRD
193  23  23
194  49 PRD
195  24  24
196  49 PRD
197  25  25
198  65  x
199  43 RCL
200  21  21
201  45 Y^X
202  03  3
203  75  -
204  01  1
205  95  =
206  94 +/-
207  42 STO
208  46  46
```

$\frac{12}{h^3} D_{ij}$

```
209  43 RCL
210  42  42
211  85  +
212  43 RCL
213  43  43
214  95  =
215  65  x
216  43 RCL
217  46  46
218  85  +
219  43 RCL
220  22  22
221  65  x
222  43 RCL
223  44  44
224  85  +
225  43 RCL
226  23  23
227  65  x
228  43 RCL
229  45  45
230  95  =
231  42 STO
232  27  27
233  75  -
234  02  2
235  65  x
236  43 RCL
237  22  22
238  65  x
239  43 RCL
```

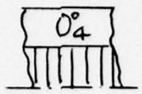
Tape #6 Flexural Rigidity

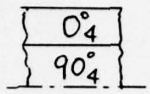
	240	44	44
	241	95	=
	242	42	STO
	243	28	28
	244	43	RCL
	245	42	42
	246	75	-
	247	43	RCL
	248	43	43
	249	95	=
	250	65	×
	251	43	RCL
	252	46	46
	253	75	-
	254	43	RCL
	255	23	23
	256	65	×
	257	43	RCL
	258	45	45
	259	95	=
	260	42	STO
	261	29	29
	262	75	-
	263	43	RCL
	264	42	42
	265	65	×
	266	43	RCL
	267	46	46
	268	85	+
	269	02	2
	270	65	×
	271	43	RCL
	272	43	43
	273	65	×
	274	43	RCL
	275	46	46
	276	95	=
	277	42	STO
	278	30	30
	279	43	RCL
	280	24	24
	281	65	×
	282	43	RCL
	283	44	44
	284	55	÷
	285	02	2
	286	85	+
	287	43	RCL
	288	25	25
	289	65	×
	290	43	RCL
	291	45	45
	292	95	=
	293	94	+/-
	294	42	STO
	295	31	31
	296	85	+
	297	02	2
	298	65	×
	299	43	RCL
	300	25	25
	301	65	×
	302	43	RCL
	303	45	45
	304	95	=
	305	42	STO
	306	32	32
$\lvert D \rvert$	307	43	RCL
	308	27	27
	309	65	×
	310	43	RCL
	311	28	28
	312	65	×
	313	43	RCL
	314	30	30
	315	85	+
	316	43	RCL
	317	29	29
	318	65	×
	319	43	RCL

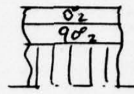
	320	31	31
	321	65	×
	322	43	RCL
	323	32	32
	324	65	×
	325	02	2
	326	75	-
	327	43	RCL
	328	28	28
	329	65	×
	330	43	RCL
	331	31	31
	332	33	X²
	333	75	-
	334	43	RCL
	335	27	27
	336	65	×
	337	43	RCL
	338	32	32
	339	33	X²
	340	75	-
	341	43	RCL
	342	30	30
	343	65	×
	344	43	RCL
	345	29	29
	346	33	X²
	347	95	=
	348	42	STO
	349	39	39
d^*_{ij}	350	43	RCL
	351	28	28
	352	65	×
	353	43	RCL
	354	30	30
	355	75	-
	356	43	RCL
	357	32	32
	358	33	X²
	359	95	=
	360	42	STO
	361	33	33
	362	43	RCL
	363	27	27
	364	65	×
	365	43	RCL
	366	28	28
	367	75	-
	368	43	RCL
	369	29	29
	370	33	X²
	371	95	=
	372	42	STO
	373	36	36
	374	43	RCL
	375	27	27
	376	65	×
	377	43	RCL
	378	30	30
	379	75	-
	380	43	RCL
	381	31	31
	382	33	X²
	383	95	=
	384	42	STO
	385	34	34
	386	43	RCL
	387	29	29
	388	65	×
	389	43	RCL
	390	32	32
	391	75	-
	392	43	RCL
	393	28	28
	394	65	×
	395	43	RCL
	396	31	31
	397	95	=
	398	42	STO
	399	37	37

	400	43	RCL
	401	31	31
	402	65	×
	403	43	RCL
	404	32	32
	405	75	-
	406	43	RCL
	407	29	29
	408	65	×
	409	43	RCL
	410	30	30
	411	95	=
	412	42	STO
	413	35	35
	414	43	RCL
	415	29	29
	416	65	×
	417	43	RCL
	418	31	31
	419	75	-
	420	43	RCL
	421	27	27
	422	65	×
	423	43	RCL
	424	32	32
	425	95	=
	426	42	STO
	427	38	38
d_{ij}	428	43	RCL
	429	51	51
	430	45	YX
	431	03	3
	432	65	×
	433	02	2
	434	55	÷
	435	03	3
	436	95	=
	437	42	STO
	438	51	51
	439	65	×
	440	43	RCL
	441	39	39
	442	95	=
	443	35	1/X
	444	49	PRD
	445	33	33
	446	49	PRD
	447	34	34
	448	49	PRD
	449	35	35
	450	49	PRD
	451	36	36
	452	49	PRD
	453	37	37
	454	49	PRD
	455	38	38
	456	01	1
	457	95	=
	458	91	R/S
E^f_1	459	76	LBL
	460	17	B'
	461	43	RCL
	462	33	33
	463	65	×
	464	43	RCL
	465	51	51
	466	95	=
	467	35	1/X
	468	91	R/S
E^f_2	469	76	LBL
	470	18	C'
	471	43	RCL
	472	34	34
	473	65	×
	474	43	RCL
	475	51	51
	476	95	=
	477	35	1/X
	478	91	R/S
	479	00	0

 $[0_8]_s$

 $[0_4/\text{Core}_4]_s$

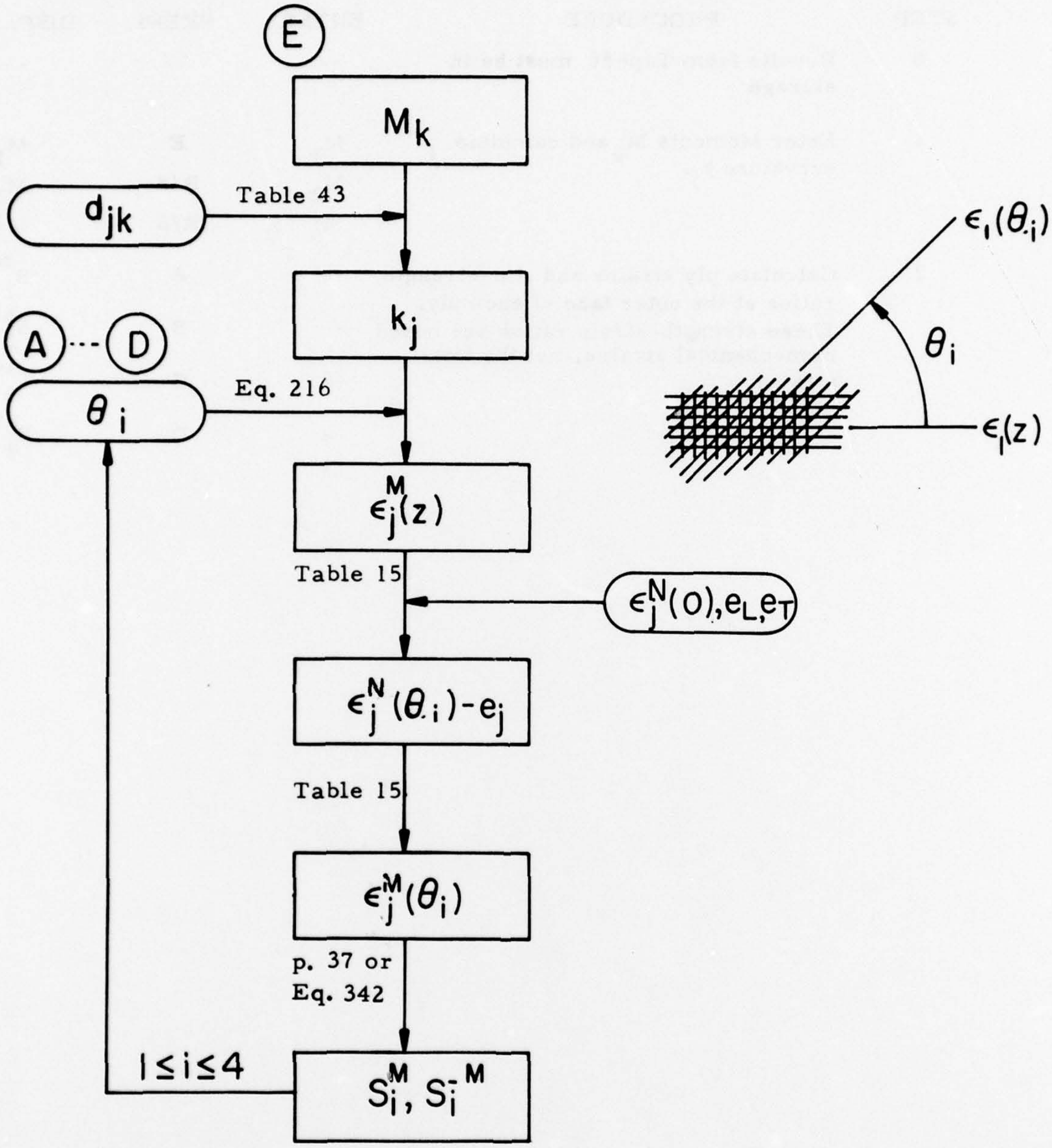
 $[0_4/90_4]_s$

 $[0_2/90_2/\text{Core}]_s$

	0. 00	0. 00	0. 00	0. 00	00
	181.81114 09	181.81114 09	181.81114 09	181.81114 09	01
	10.346159 09	10.346159 09	10.346159 09	10.346159 09	02
	2.8969244 09	2.8969244 09	2.8969244 09	2.8969244 09	03
	0. 00	0. 00	0. 00	0. 00	04
	0. 00	0. 00	0. 00	0. 00	05
	0. 00	0. 00	0. 00	0. 00	06
	0. 00	0. 00	0. 00	0. 00	07
	0. 00	0. 00	0. 00	0. 00	08
	0. 00	0. 00	0. 00	0. 00	09
	0. 00	0. 00	0. 00	0. 00	10
	0. 00	0. 00	0. 00	0. 00	11
	0. 00	0. 00	0. 00	0. 00	12
	0. 00	0. 00	90. 00	90. 00	13
θ_1, z_1	1. -03	1. -03	500. -06	750. -06	14
	40. 06	40. 06	0. 00	0. 00	15
θ_2, z_2	3.8447501 00	30.750001 03	1. -03	1. -03	16
	68. 06	68. 06	68. 06	68. 06	17
	2.8358135 03	22.65575 06	2.828126 03	22.625 06	18
	10.3 09	10.3 09	10.3 09	10.3 09	19
	5.6677823 03	22.65575 06	5.656251 03	22.625 06	20
z_c	0. 00	500. -06	0. 00	500. -06	21
	1. 00	875. -03	750. -03	281.25-03	22
	1. 00	875. -03	1. 00	875. -03	23
	0. 00	0. 00	0. 00	0. 00	24
	0. 00	0. 00	0. 00	0. 00	25
	0. 00	0. 00	0. 00	0. 00	26
	181.81114 09	159.08475 09	160.37802 09	108.18108 09	27
	10.346159 09	9.0528889 09	31.779281 09	59.956555 09	28
	2.8969244 09	2.5348089 09	2.8969244 09	2.5348089 09	29
$\frac{12D_{ij}}{h^3}$	7.17 09	6.27375 09	7.17 09	6.27375 09	30
	0. 00	0. 00	0. 00	0. 00	31
	0. 00	0. 00	0. 00	0. 00	32
	8.2872928-03	9.4711918-03	9.3683286-03	13.87939-03	33
	145.63107-03	166.43551-03	47.278412-03	25.042923-03	34
	-2.320442-03	-2.6519337-03	-853.99478-06	-586.78489-06	35
d_{ij}	209.20502-03	239.09145-03	209.20502-03	239.09145-03	36
	0. 00	0. 00	0. 00	0. 00	37
	0. 00	0. 00	0. 00	0. 00	38
	13.426934 30	8.9949971 30	36.483153 30	40.652267 30	39
	0. 00	0. 00	0. 00	0. 00	40
	125. -06	125. -06	125. -06	125. -06	41
	49.487787 09	49.487787 09	49.487787 09	49.487787 09	42
	26.880431 09	26.880431 09	26.880431 09	26.880431 09	43
	85.73249 09	85.73249 09	85.73249 09	85.73249 09	44
	19.710431 09	19.710431 09	19.710431 09	19.710431 09	45
$1-\left(\frac{2z_c}{h}\right)^3$	1. 00	875. -03	1. 00	875. -03	46
	0. 00	0. 00	0. 00	0. 00	47
	101.62602-18	101.62602-18	101.62602-18	101.62602-18	48
	0. 00	0. 00	0. 00	0. 00	49
	1. -09	875. -12	875. -12	578.125-12	50
$\frac{h^3}{12}$	666.66667-12	666.66667-12	666.66667-12	666.66667-12	51
	0. 00	0. 00	0. 00	0. 00	52
	0. 00	0. 00	0. 00	0. 00	53
	12.004384 03	12.004384 03	12.004384 03	12.004384 03	54
	10.680652 03	10.680652 03	10.680652 03	10.680652 03	55
	-3.0691032 03	-3.0691032 03	-3.0691032 03	-3.0691032 03	56
	11.117842 03	11.117842 03	11.117842 03	11.117842 03	57
	60.646995 00	60.646995 00	60.646995 00	60.646995 00	58
	216.59641 00	216.59641 00	216.59641 00	216.59641 00	59

TAPE #7

FLEXURAL STRENGTH OF SYMMETRIC SANDWICH PLATES



USER INSTRUCTION

TAPE #7: FLEXURAL STRENGTH OF SYMMETRIC SANDWICH PLATES

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
0	Results from Tape #6 must be in storage	--	--	--
1	Enter Moments M_k and calculate curvature k_j.	M_1	E	M_1
		M_2	R/S	M_2
		M_6	R/S	1.00
2	Calculate ply strains and the strength ratios at the outer face of each ply. These strength-strain ratios are based onmechanical strains, not the total strains.	--	A	S_1^M
		--	B	S_2^M
		--	C	S_3^M
		--	D	S_4^M

Tape# 7   Title FLEXURAL STRENGTH OF SYMMETRIC SANDWICH PLATES

KEYS		STORAGE MEMORIES				
A S_1^M	0		20	z_4	40	z_i, b, b/2a, S_i
	1	M_1	21	z_c	41	h_o
A'	2	M_2	22		42	S_1^M
	3	M_6	23		43	S_2^M
B S_2^M	4	k_1	24		44	S_3^M
	5	k_2	25		45	S_4^M
B'	6	k_6	26	M_6	46	$1-\left(\frac{2z_c}{h}\right)^3$
	7	$\epsilon_1^M(z)$	27	$\epsilon_1^M(\theta_i)$	47	S_1^{-M}
C S_3^M	8	$\epsilon_2^M(z)$	28	$\epsilon_2^M(\theta_i)$	48	S_2^{-M}
	9	$\epsilon_6^M(z)$	29	$\epsilon_6^M(\theta_i)$	49	S_3^{-M}
C'	10	ϵ_1^N	30	$\epsilon_1^N(\theta_i) - e_L$	50	θ_i, S_4^{-M}
	11	ϵ_2^N	31	$\epsilon_2^N(\theta_i) - e_T$	51	$h/2, h^3/12$
D S_4^M	12	ϵ_6^N	32	$\epsilon_6^N(\theta_i)$	52	e_L
	13	θ_1	33	d_{11}	53	e_T
D'	14	z_1	34	d_{22}	54	G_{11}
	15	θ_2	35	d_{12}	55	G_{22}
E M_k	16	z_2	36	d_{66}	56	G_{12}
	17	θ_3	37	d_{16}	57	G_{66}
E'	18	z_3	38	d_{26}	58	G_1
	19	θ_4	39	D , a, 1/a, $\sqrt{\ }$, S_i^-	59	G_2

Tape #7 Flexural Strength

M_k	000	76	LBL
	001	15	E
	002	42	STO
	003	01	01
	004	91	R/S
	005	42	STO
	006	02	02
	007	91	R/S
	008	42	STO
	009	03	03
k_j	010	65	×
	011	43	RCL
	012	37	37
	013	85	+
	014	43	RCL
	015	01	01
	016	65	×
	017	43	RCL
	018	33	33
	019	85	+
	020	43	RCL
	021	02	02
	022	65	×
	023	43	RCL
	024	35	35
	025	95	=
	026	42	STO
	027	04	04
	028	43	RCL
	029	01	01
	030	65	×
	031	43	RCL
	032	35	35
	033	85	+
	034	43	RCL
	035	02	02
	036	65	×
	037	43	RCL
	038	34	34
	039	85	+
	040	43	RCL
	041	03	03
	042	65	×
	043	43	RCL
	044	38	38
	045	95	=
	046	42	STO
	047	05	05
	048	43	RCL
	049	01	01
	050	65	×
	051	43	RCL
	052	37	37
	053	85	+
	054	43	RCL
	055	02	02
	056	65	×
	057	43	RCL
	058	38	38
	059	85	+
	060	43	RCL
	061	03	03
	062	65	×
	063	43	RCL
	064	36	36
	065	95	=
	066	42	STO
	067	06	06
	068	01	1
	069	95	=
	070	91	R/S
S_1^M	071	76	LBL
	072	11	A
	073	43	RCL
	074	13	13
	075	42	STO
	076	50	50
	077	43	RCL
	078	14	14
	079	71	SBR
	080	35	1/X
	081	42	STO
	082	47	47
	083	43	RCL
	084	40	40
	085	42	STO
	086	42	42
	087	91	R/S
S_2^M	088	76	LBL
	089	12	B
	090	43	RCL
	091	15	15
	092	42	STO
	093	50	50
	094	43	RCL
	095	16	16
	096	71	SBR
	097	35	1/X
	098	42	STO
	099	48	48
	100	43	RCL
	101	40	40
	102	42	STO
	103	43	43
	104	91	R/S
S_3^M	105	76	LBL
	106	13	C
	107	43	RCL
	108	17	17
	109	42	STO
	110	50	50
	111	43	RCL
	112	18	18
	113	71	SBR
	114	35	1/X
	115	42	STO
	116	49	49
	117	43	RCL
	118	40	40
	119	42	STO
	120	44	44
	121	91	R/S
S_4^M	122	76	LBL
	123	14	D
	124	43	RCL
	125	19	19
	126	42	STO
	127	50	50
	128	43	RCL
	129	20	20
	130	71	SBR
	131	35	1/X
	132	42	STO
	133	50	50
	134	43	RCL
	135	40	40
	136	42	STO
	137	45	45
	138	91	R/S
$\epsilon_j^M(z_i)$	139	76	LBL
	140	35	1/X
	141	42	STO
	142	40	40
	143	65	×
	144	43	RCL
	145	04	04
	146	95	=
	147	42	STO
	148	07	07
	149	01	1
	150	09	9
	151	66	PAU
	152	43	RCL
	153	40	40
	154	65	×
	155	43	RCL
	156	05	05
	157	95	=
	158	42	STO
	159	08	08
	160	43	RCL
	161	40	40
	162	65	×
	163	43	RCL
	164	06	06
	165	95	=
	166	42	STO
	167	09	09
$\epsilon_j^N(\theta_i) - e_j$	168	02	2
	169	49	PRD
	170	50	50
	171	43	RCL
	172	10	10
	173	85	+
	174	43	RCL
	175	11	11
	176	95	=
	177	55	÷
	178	02	2
	179	95	=
	180	42	STO
	181	39	39
	182	75	-
	183	43	RCL
	184	11	11
	185	95	=
	186	42	STO
	187	40	40
	188	65	×
	189	43	RCL
	190	50	50
	191	39	COS
	192	85	+
	193	43	RCL
	194	39	39
	195	85	+
	196	43	RCL
	197	12	12
	198	65	×
	199	43	RCL
	200	50	50
	201	38	SIN
	202	55	÷
	203	02	2
	204	75	-
	205	43	RCL
	206	52	52
	207	95	=
	208	42	STO
	209	30	30
	210	75	-
	211	02	2
	212	65	×
	213	43	RCL
	214	39	39
	215	85	+
	216	43	RCL
	217	52	52
	218	85	+
	219	43	RCL
	220	53	53
	221	95	=
	222	94	+/-
	223	42	STO
	224	31	31
	225	43	RCL
	226	12	12
	227	65	×
	228	43	RCL
	229	50	50
	230	39	COS
	231	75	-
	232	43	RCL
	233	40	40
	234	65	×
	235	02	2
	236	65	×
	237	43	RCL
	238	50	50
	239	38	SIN

Tape #7 Flexural Strength

240	95	=
241	42	STO
242	32	32

$\epsilon_j^M(\theta_i)$

243	43	RCL
244	07	07
245	85	+
246	43	RCL
247	08	08
248	95	=
249	55	÷
250	02	2
251	95	=
252	42	STO
253	39	39
254	75	-
255	43	RCL
256	08	08
257	95	=
258	42	STO
259	40	40
260	65	×
261	43	RCL
262	50	50
263	39	COS
264	85	+
265	43	RCL
266	39	39
267	85	+
268	43	RCL
269	09	09
270	65	×
271	43	RCL
272	50	50
273	38	SIN
274	55	÷
275	02	2
276	95	=
277	42	STO
278	27	27
279	75	-
280	43	RCL
281	07	07
282	75	-
283	43	RCL
284	08	08
285	95	=
286	94	+/-
287	42	STO
288	28	28
289	43	RCL
290	09	09
291	65	×
292	43	RCL
293	50	50
294	39	COS
295	75	-
296	43	RCL
297	40	40
298	65	×
299	02	2
300	65	×
301	43	RCL
302	50	50
303	38	SIN
304	95	=
305	42	STO
306	29	29

S_i^M

307	33	X²
308	65	×
309	43	RCL
310	57	57
311	85	+
312	43	RCL
313	54	54
314	65	×
315	43	RCL
316	27	27
317	33	X²
318	85	+
319	02	2
320	65	×
321	43	RCL
322	56	56
323	65	×
324	43	RCL
325	27	27
326	65	×
327	43	RCL
328	28	28
329	85	+
330	43	RCL
331	55	55
332	65	×
333	43	RCL
334	28	28
335	33	X²
336	95	=
337	42	STO
338	39	39
339	43	RCL
340	58	58
341	65	×
342	43	RCL
343	27	27
344	85	+
345	43	RCL
346	59	59
347	65	×
348	43	RCL
349	28	28
350	85	+
351	02	2
352	65	×
353	53	(
354	43	RCL
355	54	54
356	65	×
357	43	RCL
358	27	27
359	65	×
360	43	RCL
361	30	30
362	85	+
363	43	RCL
364	56	56
365	65	×
366	53	(
367	43	RCL
368	27	27
369	65	×
370	43	RCL
371	31	31
372	85	+
373	43	RCL
374	28	28
375	65	×
376	43	RCL
377	30	30
378	54	)
379	85	+
380	43	RCL
381	55	55
382	65	×
383	43	RCL
384	28	28
385	65	×
386	43	RCL
387	31	31
388	85	+
389	43	RCL
390	57	57
391	65	×
392	43	RCL
393	29	29
394	65	×
395	43	RCL
396	32	32
397	95	=
398	55	÷
399	43	RCL
400	39	39
401	55	÷
402	02	2
403	95	=
404	42	STO
405	40	40
406	01	1
407	75	-
408	43	RCL
409	54	54
410	65	×
411	43	RCL
412	30	30
413	33	X²
414	75	-
415	02	2
416	65	×
417	43	RCL
418	56	56
419	65	×
420	43	RCL
421	30	30
422	65	×
423	43	RCL
424	31	31
425	75	-
426	43	RCL
427	55	55
428	65	×
429	43	RCL
430	31	31
431	33	X²
432	75	-
433	43	RCL
434	57	57
435	65	×
436	43	RCL
437	32	32
438	33	X²
439	75	-
440	43	RCL
441	58	58
442	65	×
443	43	RCL
444	30	30
445	75	-
446	43	RCL
447	59	59
448	65	×
449	43	RCL
450	31	31
451	95	=
452	55	÷
453	43	RCL
454	39	39
455	85	+
456	43	RCL
457	40	40
458	33	X²
459	95	=
460	34	√X
461	42	STO
462	39	39
463	75	-
464	43	RCL
465	40	40
466	95	=
467	42	STO
468	40	40
469	75	-
470	02	2
471	65	×
472	43	RCL
473	39	39
474	95	=
475	94	+/-
476	92	RTN
477	00	0
478	00	0
479	00	0

	0. 00	0. 00	0. 00	0. 00	00
M_k	1. 00	1. 00	1. 00	1. 00	01
	0. 00	0. 00	0. 00	0. 00	02
	0. 00	0. 00	0. 00	0. 00	03
	8.2872928-03	9.4711918-03	9.3683286-03	13.87939-03	04
	-2.320442-03	-2.6519337-03	-853.99478-06	-586.78489-06	05
	0. 00	0. 00	0. 00	0. 00	06
	8.2872928-06	9.4711918-06	9.3683286-06	13.87939-06	07
	-2.320442-06	-2.6519337-06	-853.99478-09	-586.78489-09	08
	0. 00	0. 00	0. 00	0. 00	09
	0. 00	0. 00	0. 00	0. 00	10
	0. 00	0. 00	0. 00	0. 00	11
	0. 00	0. 00	0. 00	0. 00	12
	0. 00	0. 00	90. 00	90. 00	13
	1. -03	1. -03	500. -06	750. -06	14
	40. 06	40. 06	0. 00	0. 00	15
	3.8447501 00	30.750001 03	1. -03	1. -03	16
	68. 06	68. 06	68. 06	68. 06	17
	2.8358135 03	22.65575 06	22.625 06	22.625 06	18
	10.3 09	10.3 09	10.3 09	10.3 09	19
	5.6677823 03	22.65575 06	22.625 06	22.625 06	20
	0. 00	500. -06	0. 00	500. -06	21
	1. 00	875. -03	750. -03	281.25-03	22
	1. 00	875. -03	1. 00	875. -03	23
	0. 00	0. 00	0. 00	0. 00	24
	0. 00	0. 00	0. 00	0. 00	25
	0. 00	0. 00	0. 00	0. 00	26
	8.2872928-06	9.4711918-06	9.3683286-06	13.87939-06	27
	-2.320442-06	-2.6519337-06	-853.99478-09	-586.78489-09	28
	0. 00	0. 00	0. 00	0. 00	29
	0. 00	0. 00	0. 00	0. 00	30
	0. 00	0. 00	0. 00	0. 00	31
	0. 00	0. 00	0. 00	0. 00	32
	8.2872928-03	9.4711918-03	9.3683286-03	13.87939-03	33
	145.63107-03	166.43551-03	47.278412-03	25.042923-03	34
	-2.320442-03	-2.6519337-03	-853.99478-06	-586.78489-06	35
	209.20502-03	239.09145-03	209.20502-03	239.09145-03	36
	0. 00	0. 00	0. 00	0. 00	37
	0. 00	0. 00	0. 00	0. 00	38
	1. 03	875. 00	964.5143 00	667.40582 00	39
	1. 03	875. 00	791.97978 00	516.39171 00	40
	125. -06	125. -06	125. -06	125. -06	41
S^M	1. 03	875. 00	835.69432 00	374.19028 00	42
	26.880431 09	26.880431 09	791.97978 00	516.39171 00	43
	85.73249 09	85.73249 09	85.73249 09	85.73249 09	44
	19.710431 09	19.710431 09	19.710431 09	19.710431 09	45
	1. 00	875. -03	1. 00	875. -03	46
S^{-M}	1. 03	875. 00	4.8092482 03	2.2499333 03	47
	101.62602-18	101.62602-18	1.1370488 03	818.41992 00	48
	0. 00	0. 00	0. 00	0. 00	49
	0. 00	0. 00	0. 00	0. 00	50
	666.66667-12	666.66667-12	666.66667-12	666.66667-12	51
	0. 00	0. 00	0. 00	0. 00	52
	0. 00	0. 00	0. 00	0. 00	53
	12.004384 03	12.004384 03	12.004384 03	12.004384 03	54
	10.680652 03	10.680652 03	10.680652 03	10.680652 03	55
	-3.0691032 03	-3.0691032 03	-3.0691032 03	-3.0691032 03	56
	11.117842 03	11.117842 03	11.117842 03	11.117842 03	57
	60.646995 00	60.646995 00	60.646995 00	60.646995 00	58
	216.59641 00	216.59641 00	216.59641 00	216.59641 00	59

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